DNR REMEDIATION & REDEVELOPMENT PROGRAM
GUIDANCE FOR PUBLIC COMMENT

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DOCUMENT TRACKING NUMBER

RR-800

DOCUMENT TITLE

Vapor Intrusion Guidance

BACKGROUND/SUMMARY

This guidance is for persons who investigate, remediate and mitigate contaminated sites under Wisconsin Statute (Wis. Stat.) ch. 292 and Wisconsin Administrative (Wis. Admin.) Code chs. NR 700 - 799. It applies to sites with contaminated vapor that has migrated or has the potential to migrate to current or future buildings. It includes conditions that indicate an investigation of the vapor intrusion pathway is necessary and guidelines on response actions.

RR-800 includes the following updates:

- Vapor intrusion conceptual site model
- Variables affecting vapor intrusion
- Recommendations on vapor investigations
- Soil screening distance from chlorinated solvents
- Groundwater screening criteria for tetrachloroethene (PCE) and trichloroethene (TCE)
- Groundwater screening criteria for other contaminants
- Information on passive sampling in lieu of evacuated canister sampling
- Evacuated canister sub-slab vapor sampling
- Assessing parking garages and elevators
- Example vapor investigation status map
- Recommendations on vapor mitigation
- Active notifications, including telemetry
- Building decision matrix including DHS-recommended time frames for immediate and interim response actions
- Assignment of vapor continuing obligations at interim action
- Educational and visually descriptive figures
- History of dry cleaners and other sources of chlorinated solvents
- DHS letters from 2017, 2021 and 2022

PUBLIC COMMENT PERIOD CLOSE DATE

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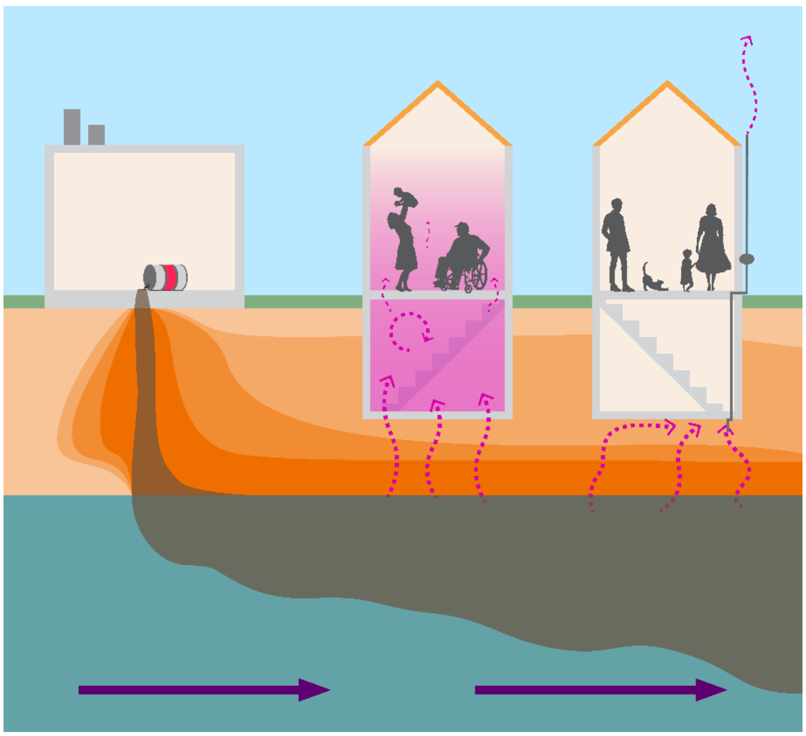
Please submit comments to dnrrrguidance@wisconsin.gov, use subject line: “RR-800 Comments”

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Purpose
This guidance is for persons who investigate, remediate and mitigate contaminated sites under Wisconsin Statute (Wis. Stat.) ch. 292 and Wisconsin Administrative (Wis. Admin.) Code chs. NR 700 - 799. It applies to sites with contaminated vapor that has migrated or has the potential to migrate to current or future buildings. It includes conditions that indicate an investigation of the vapor intrusion pathway is necessary and guidelines on response actions.



Vapor intrusion

generally refers to subsurface contamination that can volatilize and the vapors enter the breathing space of buildings. Vapor intrusion can also occur when contaminated groundwater infiltrates buildings and contaminants directly volatilize into the indoor air. Vapors can migrate through air space in permeable soils, fractures in bedrock or clay tills, utilities, sumps, or cracks in a building foundation. Vapor intrusion can also occur through conduits.

Exposure to contaminants due to vapor intrusion may present human health risks. When certain contaminants are present, such as trichloroethylene, even short-duration exposures may present acute health risks. Evaluation and mitigation of the vapor intrusion pathway are important aspects of the investigation and cleanup process.

The DNR partners with the Wisconsin Department of Health Services (DHS) and local health departments regarding short-term (acute) and long-term (chronic) risks to human health related to vapor intrusion, as well as determining appropriate immediate and interim recommendations (e.g., ventilation, mitigation) at affected sites. The DHS and local health departments assist the DNR, responsible parties and environmental consultants with health risk communications, including supportive literature.

Related Guidance
Wisconsin Department of Natural Resources (DNR) publications and forms referenced in this document include a number beginning with “RR-” or “4400-.” Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching “vapor.”

This document is intended solely as guidance and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

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1 Introduction

1.1 Acronyms and Abbreviations

1,1,1-TCA	1,1,1-trichloroethane
1,2-DCA	1,2-dichloroethane
1,2-DCE	1,2-dichloroethylene, *cis-* or *trans-* (aka 1,2-dichloroethene, *cis-* or *trans-*)
AARST	American Association of Radon Scientists and Technologists (aka IEA)
AER	air exchange rate
AF	attenuation factor
ANSI	American National Standards Institute
APU	air purification unit
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineering
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BPC	building pressure cycling
BRRTS	Bureau for Remediation and Redevelopment Tracking System
BTEX	benzene, toluene, ethylbenzene, and xylenes
C	carcinogen for inhalation pathway
CO	continuing obligation
COC	contaminant of concern
CSM	conceptual site model
CT	carbon tetrachloride
CVOCs	chlorinated volatile organic compounds
DCDFM	dichlorodifluoromethane
DERP	Dry Cleaner Environmental Response Program
DHS	Wisconsin Department of Health Services
DNR	Wisconsin Department of Natural Resources
EDB	ethylene dibromide
ELA	effective leakage area
ESTCP	Environmental Security Technology Certification Program (Department of Defense)
FD	floor drain
GC/ECD	gas chromatography/electron capture detector
GC/MS	gas chromatography/mass spectrometer
GRO	gasoline range organics
GW	groundwater
HI	hazard index
HPV	high purge volume
HVAC	heating, ventilation, and air conditioning
IA	indoor air
IEA	Indoor Environments Association (aka AARST)
ITRC	Interstate Technology Regulatory Council
ITS	indicators, tracers, and surrogates
LEL	lower explosive limit
LIF	laser induced fluorescence

LNAPL	light non-aqueous phase liquid
LOE	lines of evidence
LOQ	limit of quantitation
LPG	lateral plumbing gas
MTBE	methyl tert-butyl ether
NAPL	non-aqueous phase liquid
NAVFAC	Naval Facilities Engineering Command
NC	non-carcinogen for inhalation pathway
ND	not detected
NRPP	National Radon Proficiency Program
OA	outdoor air
OM	order of magnitude
OM&M	operation, monitoring, and maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAHs	polycyclic aromatic hydrocarbons
PAL	preventive action limit
PECFA	Petroleum Environmental Cleanup Fund Award
PFAS	per- and polyfluoroalkyl substance
PCBs	polychlorinated biphenyls
PCE	tetrachloroethylene, (aka tetrachloroethene, perchloroethylene, perc)
PFE	pressure field extension
PID	photoionization detector
PVC	poly vinyl chloride
PVOCs	petroleum volatile organic compounds
QA/QC	quality assurance/quality control
RCL	residual contaminant level
RL	reporting limit
RME	reasonable maximum exposure
RP	responsible party
RPD	relative percent difference
RRM	rapid response measures
RR Program	Remediation and Redevelopment Program
RRSM	Remediation and Redevelopment Sites Map
RTA	real time analysis
SCRD	State Coalition for the Remediation of Dry Cleaners
SG	soil gas
SMDS	sub-membrane depressurization system
SSAF	site-specific attenuation factor
SSDS	sub-slab depressurization system
SSG	sanitary sewer gas
SSGSL	sanitary sewer gas screening level
SSV	sub-slab vapor
SSVS	sub-slab venting system
SVE	soil vapor extraction

TAT	turnaround time
TCE	trichloroethylene (aka trichloroethene)
TNI	The NELAC (National Environmental Laboratory Accreditation Conference) Institute
TPHs	total petroleum hydrocarbons
UR	uptake rate
U.S. EPA	United States Environmental Protection Agency
UST	underground storage tank
VAL	vapor action level
VI	vapor intrusion
VIM	vapor intrusion mitigation
VISL	vapor intrusion screening level (calculator)
VMS	vapor mitigation system
VRSL	vapor risk screening level
VOCs	volatile organic compounds
Wis. Admin. Code	Wisconsin Administrative Code
Wis. Stat.	Wisconsin Statutes

1.2 Definitions

Acute risk means the adverse effect of a toxic substance that results either from a single exposure (over the course of an 8-hour workday in a commercial/industrial setting, or 24-period in a residential setting) or multiple exposures in a short period of time (days to weeks).

Advection is the movement of a mass of fluid (gas or liquid) and the transport of contaminants by such movement. Gas moves by advection from areas of high to low pressure and is controlled by the pressure gradient and gas permeability.

Attenuation factor (AF) means the ratio of the indoor air concentration arising from vapor intrusion (VI) to the subsurface vapor concentration at a point or depth of interest in the VI pathway (Wis. Admin. Code § NR 700.03(1s)).

Chronic risk means the adverse health effects from exposure to a toxic substance over longer periods of time (years to decades).

Conceptual site model (CSM) is a comprehensive description of an individual site and the processes by which contamination may move from sources to receptors.

Contaminant of concern (COC) is the contaminant(s) related to the discharge being investigated.

Contaminated sites refer to sites and facilities that are subject to regulation under Wis. Stat. chs. 289 and 292.

Diffusion is movement of a substance (such as a contaminant) from areas of higher to lower concentration. The rate of contaminant diffusion in the soil gas is primarily controlled by the concentration gradient and the air-filled porosity.

Non-residential setting is a setting other than residential, used for commercial or industrial purposes (Wis. Admin. Code § NR 700.03(39m)).

Occupied building refers to a structure that is intended and used for occupancy by humans. This would include, for instance, homes, offices, stores, commercial and industrial buildings, etc., but would not normally include sheds, carports, pump houses, or other structures that are not intended for human occupancy.

Order of magnitude (OM) is a factor of ten. An OM greater than 1 is 1 x 10 = 10, two OM greater than 1 is 1 x 10 x 10 = 100, and so on.

Reasonable maximum exposure (RME) is the highest exposure that is reasonably expected to occur at a site. RME is considered a "semi- quantitative term, referring to the lower portion of the high end of the exposure distribution; conceptually, above the 90th percentile exposure but less than the 98th percentile exposure"[1]. RME is characterized by an exposure concentration, exposure frequency, and exposure duration.

Receptor for VI is a human occupant of a building that may be exposed to the harmful effects of vapor forming chemicals.

Residential setting is any dwelling designed or used for human habitation including single or multiple family housing, and educational, childcare, and elder care (Wis. Admin. Code § NR 700.03(49g)).

Sensitive human receptors or occupants are more susceptible to the adverse effects of exposure to toxic vapor forming chemicals. Women who are or may become pregnant are a subgroup that commonly triggers an expedited investigation and response, but sensitive human receptors can include other subgroups such as the elderly, children and others with specific conditions. The locations where these sensitive human receptors congregate include but are not limited to hospitals, schools, child and elder care facilities, elderly housing, and convalescent facilities.

Single exposure is an exposure that occurs over the course of an 8-hour workday in a commercial/industrial setting, or 24-hour period in a residential setting[2].

Vadose zone is the unsaturated portion of the subsurface above the water table. The pore space contains air as well as water at least some of the time.

Vapor action level (VAL) means the concentration of vapors from volatile compounds is at or above the 1−in−100,000 (1×10^{-05}) excess lifetime cancer risk or is at or above a hazard index (HI) of 1 for non−carcinogens for inhalation exposure (Wis. Admin. Code § NR 700.03(66p)).

Vapor intrusion (VI) generally refers to subsurface contamination that can volatilize and the vapors enter the breathing space of buildings. VI can also occur when contaminated groundwater infiltrates buildings and contaminants directly volatilize into the indoor air. Vapors can migrate through air space in permeable soils, fractures in bedrock or clay tills, utilities, sumps, or cracks in a building foundation. VI can also occur through conduits.

Vapor intrusion assessment is the broad evaluation used to arrive at a conclusion about the vapor migration pathway at a site, and this process may or may not include a vapor intrusion field investigation. A vapor intrusion assessment includes the evaluation of numerous factors including the potential for vapor forming chemicals in the subsurface, potential receptors, and other site-specific information (e.g., hydrogeologic conditions, depth or location of impacts, current land use, land covers) to make a determination on the potential for VI.

Vapor intrusion field investigation may occur within the overall VI assessment if field sampling and analysis are needed to make a determination on the vapor migration pathway at a site.

Vapor intrusion screening level (VISL) calculator is a web-based calculator utilizing the U.S. EPA's inhalation toxicity data and default input parameters to calculate screening levels regarding vapor intrusion. Input parameters can be modified to calculate Wisconsin-specific VALs and VRSLs. The calculator is available on www.epa.gov by searching "Vapor Intrusion Screening Level Calculator."

[1] U.S. EPA 2015.
[2] DHS 2022. See Appendix H.

Vapor risk screening level (VRSL) means the contaminant concentration in vapor samples collected outside a building to estimate indoor air contaminant concentrations. The VRSL is equal to the VAL divided by an appropriate AF (Wis. Admin. Code § NR 700.03(66w)).

Winter assessment period is the period between December 1 and March 31 when frost conditions, with closed doors and windows and active heating, are more likely to create maximum indoor air contaminant concentrations.

Women who are or may become pregnant are between the ages of 15 to 44 (the Centers for Disease Control references women of child-bearing age as females between 15 to 44 years old).

1.3 Units and Nomenclature

$\mu g/m^3$	Micrograms per cubic meter
µg/L	Micrograms per liter
C_{coc}	Concentration, contaminant of concern
C_i	Concentration, indoor air
C_{gw}	Concentration, groundwater
C_{soil}	Concentration, soil gas entering a building
CO_2	Carbon Dioxide
H	Henry's Law Constant
M	Mass
m	Meters
mm	Millimeter (or "mil")
mph	Miles per Hour
M_{er}	Mass contaminant entry rate
M_{min}	Minimum Laboratory Reporting Limit
m/s	Meters per second
O_2	Oxygen (molecular)
Pa	Pascal
ppb	Parts Per Billion
ppm	Parts Per Million
ppt	Parts Per Trillion
sf	Square Feet
Q_{soil}	Rate at which soil gas enters a building
t	Time
V_b	Volume of building

2 Field Investigation and Immediate and Interim Actions

2.1 Determining if a Vapor Intrusion Field Investigation Is Necessary

A vapor intrusion (VI) field investigation is required for those chemicals that are sufficiently volatile[3] and toxic[4] to be a potential VI risk (Wis. Admin. Code § NR 716.11(5)).

Chlorinated volatile organic compounds (CVOCs) and petroleum volatile organic compounds (PVOCs) are contaminant types that commonly result in the need to assess the VI pathway at contaminated sites and are specifically addressed in this guidance.

While many of the same principles used to evaluate and mitigate VI also apply to radon gas intrusion in buildings, this guidance does not address radon gas[5].

Depending upon site conditions, other volatile organic compounds (VOCs), semi-volatile contaminants, or a volatile metal such as elemental mercury may also present a risk of VI. Semi-volatile contaminants include polynuclear aromatic hydrocarbons (PAHs), dioxins and polychlorinated biphenyls (PCBs). If VI from any compound is suspected at a site, it is recommended that specific screening and investigation methods are discussed with the DNR project manager.

VISL Calculator
The U.S. EPA VISL calculator may be used to determine if the contaminants of concern at a site are sufficiently volatile and toxic to pose an inhalation risk from VI. The VISL calculator includes "yes" and "no" determinations on the question of vapor risk for over 700 chemicals and is updated on a regular basis.

The calculator is available on www.epa.gov by searching "Vapor Intrusion Screening Level Calculator."

Contaminant not a vapor risk? If the contaminant of concern (COC) is not sufficiently volatile and toxic to pose an inhalation risk per the VISL Calculator, providing this information to the DNR may serve as justification that a VI field investigation is not needed at a site.

Contaminant a vapor risk? If the COC has the potential to cause vapor intrusion, a field investigation for vapor intrusion is warranted, and immediate or interim actions may be required.

2.2 Are Immediate or Interim Actions Warranted?

Immediate or interim response actions may be necessary under Wis. Admin. Code §§ NR 708.05 and NR 708.11when vapor intrusion is a risk. Appropriate response actions may include continued investigation, immediate action (e.g., rapid response measures (RRMs)), an interim action (e.g., vapor mitigation system (VMS)) or a combination of both. Situations where immediate actions are appropriate may involve explosion hazards, TCE, or high concentrations of other contaminants. The RP may propose a strategy for combined immediate and interim actions when the risk to public health warrants expediting the timeline for investigation followed by mitigation. The DNR recommends involving the DNR project manager when considering combined investigation and mitigation. (see Section 7.2 for additional information on installing a vapor mitigation system (VMS) during sampling). See additional guidance in Sections 9 and 10 and Figure 4.

2.3 Elements of Vapor Intrusion Field Investigation and Immediate and Interim Actions

After determining that a VI field investigation is necessary, the steps shown in Figure 1 may be used. Include the elements listed below per Wis. Admin. Code ch. NR 716.

[3] Compounds with a Henry's Law constant > 10^{-5} atm m^3 mol^{-1} or vapor pressure > 1 mm Hg are typically considered volatile.
[4] Chemical toxicity is based on inhalation toxicity data as provided by U.S. EPA.
[5] More information on radon in Wisconsin is available on the Wisconsin Department of Health Services (DHS) website at www.dhs.wisconsin.gov, search "radon."

1. Scoping and Recommended CSM

Evaluate sources, receptors and pathways (Wis. Admin. Code § NR 716.07). **The DNR recommends development of a CSM for any site investigation.** This process is iterative throughout the site investigation phase. Table 1 provides the recommended elements of a CSM for VI field investigation and Appendix A provides a summary of contaminant vapor movement. Appendix C includes additional information related to dry cleaners and TCE vapor degreasers, which comprise a large percentage of sites with CVOCs contamination in Wisconsin. See Section 5.

2. Vapor Intrusion Screening

Screening involves evaluating whether the contaminant poses a vapor intrusion risk at buildings or vapor risk to other pathways (Wis. Admin. Code § NR 716.07(7)). The DNR recommends using the screening guidelines for the chemical and preliminary information available for buildings (Wis. Admin. Code § NR 716.07(7)). See Sections 2.4, 2.5 and 6. Figure 2 illustrates recommendations for screening buildings at CVOCs sites and Figure 3 gives recommendations for screening buildings at sites with PVOCs.

3. Workplan

Submit a workplan to the DNR within 60 days of receiving notification that a site investigation is required (Wis. Admin. Code § NR 716.09). Section 8 provides recommendations for investigating the vapor pathway. The DNR and DHS recommend expediting the investigation if TCE is a COC or if high vapor concentrations in occupied spaces may present an acute health risk. See letters from the DHS to DNR in Appendix H.

4. DNR Technical Assistance

Site investigations involving vapor are often complicated, iterative and take considerable time and resources. Consider requesting a technical review (with fee) from the DNR (Wis. Admin. Code ch. NR 749) for the site investigation workplan.

Is TCE Present?
TCE poses acute health risks for some receptors over very short durations. When TCE is present, the DNR recommends prioritizing vapor screening and determining demographics for buildings within days (not weeks) to allow for expedited occupant education and sampling. The DHS may assist with risk communication. See Section 3 for more information.

Outreach
Perform public participation and notification activities throughout the process (Wis. Admin. Code § NR 714.07). Site investigations involving vapor may involve occupied buildings or neighboring properties that are not owned by the responsible party (RP). While the RP must communicate with off-site property owners to obtain access for sampling and any mitigation, other notifications and participation should be considered and conducted based on site-specific factors. Communicating with potentially affected property owners, occupants and municipalities can be time intensive during VI field investigations. The DNR recommends creating a case-specific community engagement plan early in the process. See Section 4 for more information on public outreach, community engagement and property access permission.

5. Field Investigation

Expand investigation as needed to define areal and vertical extent in all affected media (Wis. Admin Code §§ NR 716.11(3)(a) and NR 716.11(5)(a)). See Sections 5.1 and 8. Figure 4 shows recommendations for initial sampling at buildings. Table 2 illustrates recommendations for follow-up sampling events at buildings. Both Figure 4 and Table 2 reflect DNR recommendations for longer duration sampling events of 10 days or more following initial sampling to accurately determine vapor concentrations and risk to receptors (see Section 8.5 and Appendix A). The exception to follow-up sampling is when mitigation measures are implemented after the initial sampling event. Appendix B includes recommended instructions for occupants.

6. Laboratory Results and Notifications

When samples are collected, the RP must provide the testing results to the DNR and to property owners and occupants within 10 business days of receiving results, unless the DNR approved an alternative schedule (Wis. Admin. Code § NR 716.14(2)). Acute risk situations may warrant immediate notification (e.g., call the DNR project manager when a COC is present at a concentration well above the VAL or other data indicate an acute risk).

7. Evaluate Need for Immediate and Interim Actions

Continuous evaluation of investigation results against vapor risk-related criteria, including VALs and VRSLs, is appropriate to determine if immediate or interim actions are warranted under Wis. Admin. Code §§ NR 708.05 and NR 708.11. See Section 2.2 for further guidance.

8. Perform Mitigation

A health risk to building occupants almost always necessitates mitigation. Sections 11 and 12 briefly discuss mitigation design and stewardship; and Appendix F addresses the topic more comprehensively. The DNR recommends installation of a sub-slab depressurization system (SSDS) to mitigate VI occurring through a building foundation. RRMs, such as use of air treatment unit(s), may be needed to reduce indoor air vapor concentrations prior to installing the VMS. Mitigation of the conduit pathway may also be needed (see Appendix F and DNR publication *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649); available at dnr.wi.gov, search "RR-649").

9. Document Immediate and Interim Actions Taken

Wis. Admin. Code §§ NR 708.05(6), NR 708.15 and NR 724.15. The DNR may assign responsibility for continuing obligations (COs) related to minimizing vapor risk at the time of approving interim actions (Wis. Stats. § 292.12(2)). See Section 12 for more information on COs.

Deliverables
Appendix G provides a list of deliverables required throughout Wis. Admin. Code chs. NR 700 - 799 relating to a case involving vapor.

10. Site Investigation Report

Document the results of the investigation (Wis. Admin. Code § NR 716.15). Consider requesting a technical review (with fee) from the DNR (Wis. Admin. Code ch. NR 749) for site investigation reports.

11. Evaluate Remedial Action Options

When contaminant concentrations in vapor exceed a VRSL, remedial action is required to reduce the mass and concentration of the volatile compounds. The primary purpose of a VMS is to interrupt the vapor intrusion pathway, not to reduce mass and concentration of the contaminants (Wis. Admin. Code § NR 726.05(8)(b)1. and (Note)).

Figure 1. Steps in Vapor Intrusion Investigation and Response

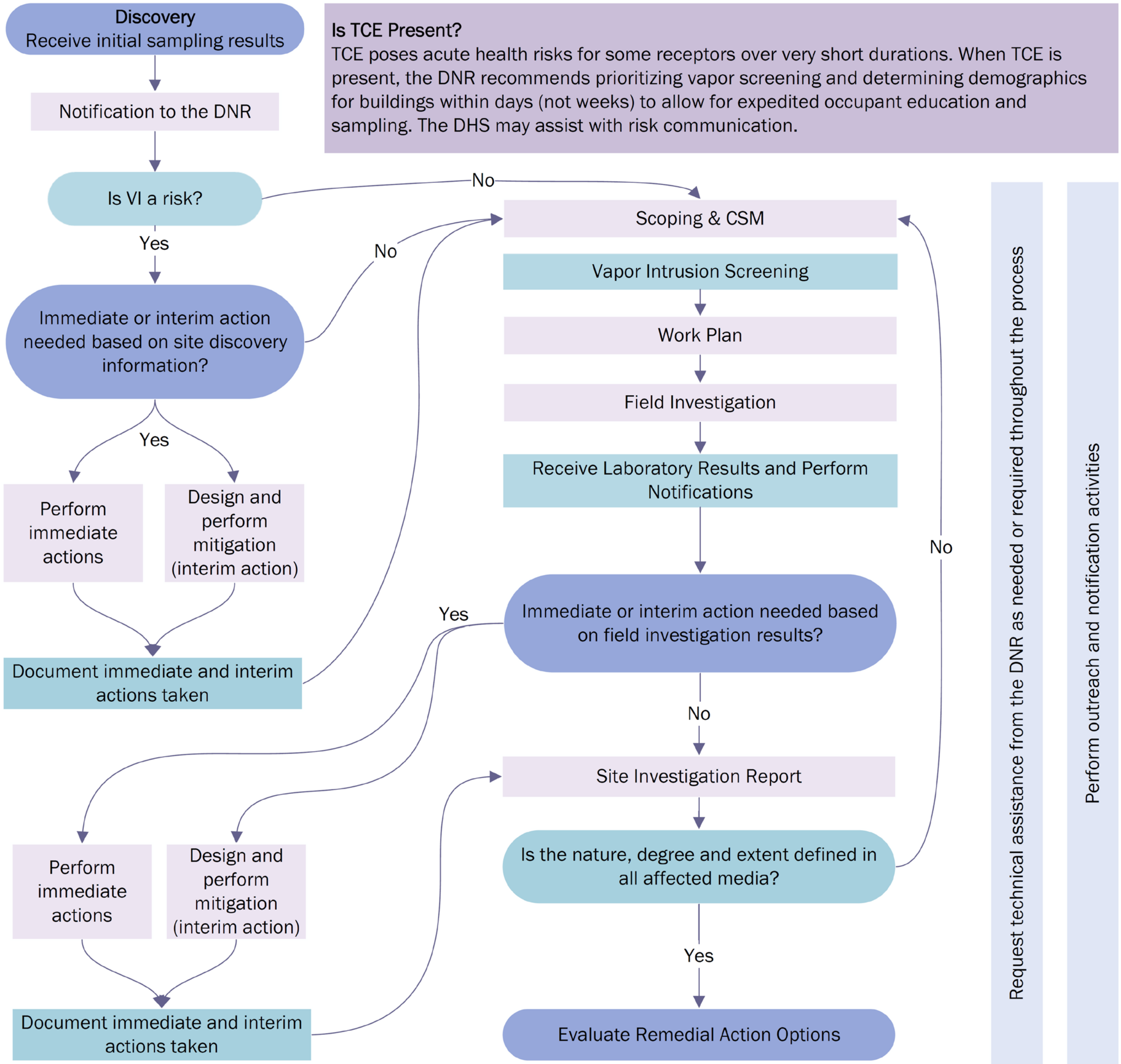


Table 1. Recommended Elements of a Vapor Intrusion Conceptual Site Model

Boundary Delineation

Based on screening distances (i.e., location of receptors compared to location of contamination)

Contaminant Identification and Characteristics

- Contaminant types (e.g., CVOCs, PVOCs, petroleum additives, methane)
- Related chemicals (e.g., PCE, TCE)

Sources of Contamination

- Release activity (e.g., dry cleaning, metal degreasing)
- Background sources (i.e., surface, sub-surface, indoor, ambient air, conduits)
- Soil (i.e., location and concentration)
- Groundwater (i.e., location and concentration, capillary fringe thickness, depth to water table, water table fluctuation, clean water lens, potable use, future groundwater conditions)
- Non-aqueous phase liquid (NAPL) (i.e., location)

Pathways - Geologic Factors

- Soil gas conductivity
- Soil moisture content in vadose zone
- Soil oxygen content in vadose zone (e.g., PVOCs)
- Natural preferential pathways (e.g., fractured bedrock & clay, karst)
- Flooding

Soil Gas Contaminant Concentrations

Pathways - Human-made Sewers, Surface and Subsurface Drainage

See *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649)

Receptors

- Occupied buildings, including infrequent occupancy
    - Building use (i.e., residential, non-residential, large and small industrial and commercial)
    - Occupant makeup (i.e., women who are or may become pregnant, sensitive populations, number)
    - Occupant disruption
- Properties/areas that could be developed, including unoccupied buildings
    - Development plans, zoning
    - Explosion potential

Buildings/Infrastructure

- Sub-grade materials (i.e., thickness, grain size)
- Foundation (i.e., type (basement, slab on grade, crawl space), depth below grade, thickness, sections, condition, presence of moisture or vapor barriers)
- Foundation walls (i.e., materials, condition)
- Points of vapor entry (See *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649))
- Layout (i.e., number of floors, division of spaces, aerial extent, building height, room height)
- Envelope (i.e., openings, leakage, aspect of openings)
- HVAC operation (i.e., type, air returns, pressure, mechanical ventilation, air exchange rate (AER))
- Elevator operation and construction of elevator pits
- Pressure status (i.e., indoor to sub-slab)
- Occupant behavior (i.e., operation of windows, doors, HVAC, contaminant use)
- Land surface effects (e.g., paved surface, uncovered ground)

Meteorological Factors

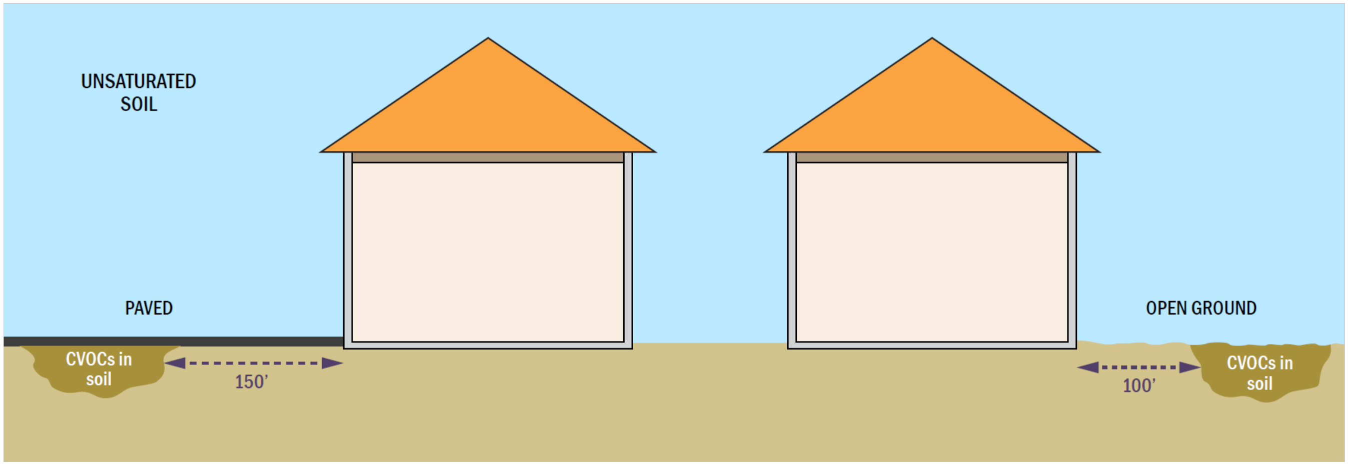
- Temperature (e.g., stack effect, frozen ground)
- Barometric pressure
- Wind (i.e., speed, direction)
- Precipitation

Future Conditions

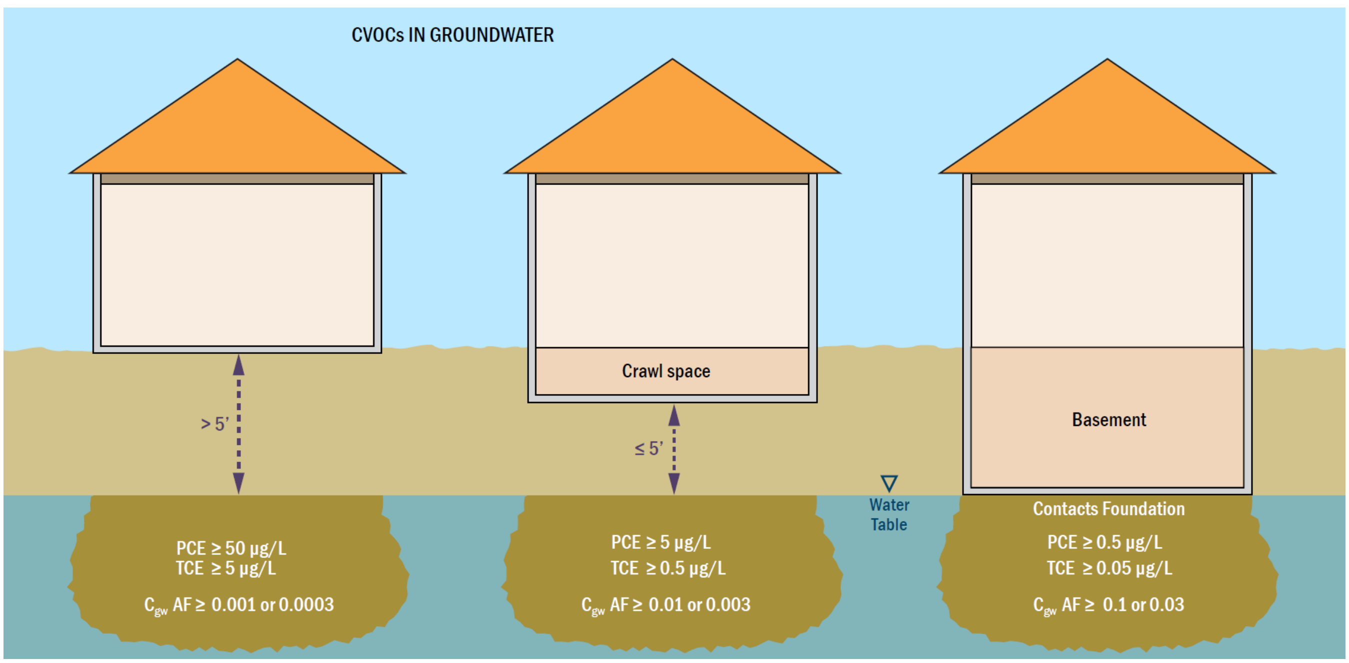
- Future groundwater conditions
- Future building conditions

2.4 Screening for CVOCs

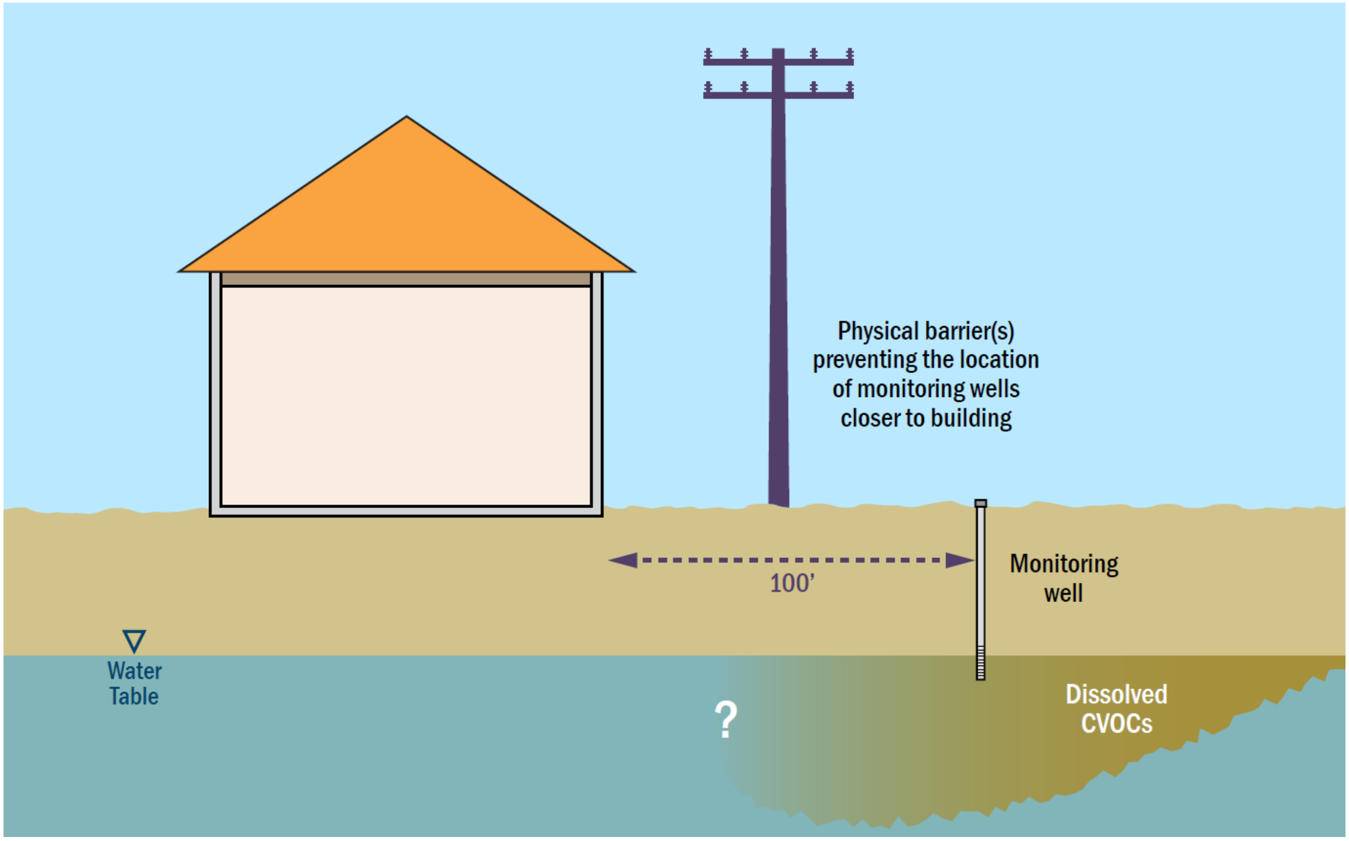
Figure 2. Scenarios Where Vapor Sampling at a Building is Recommended – CVOCs



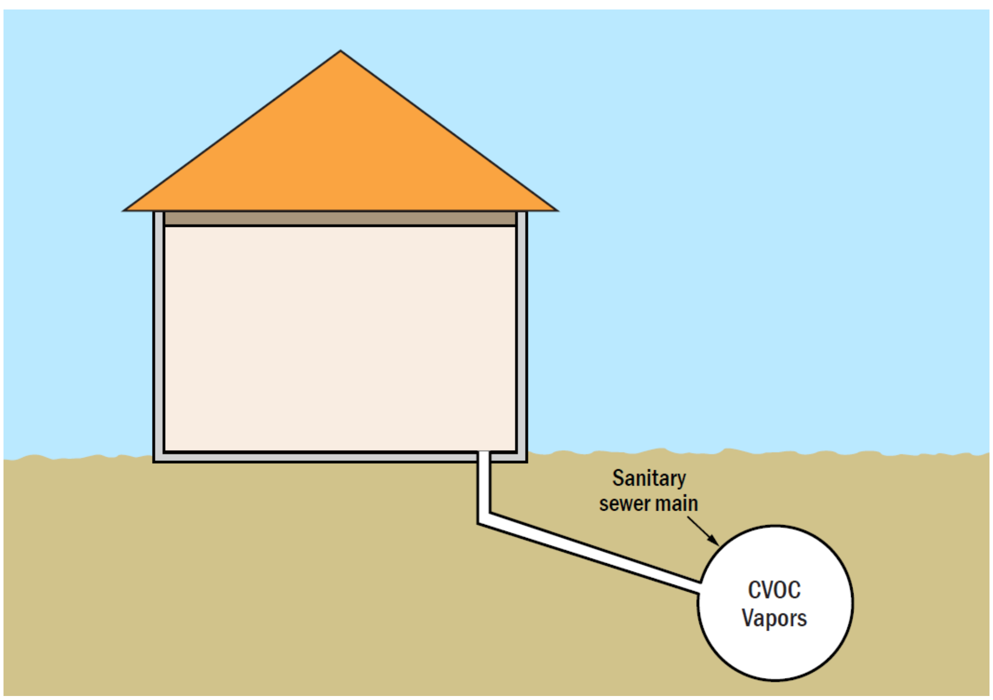
Scenario 2A. Unsaturated Soil Screening



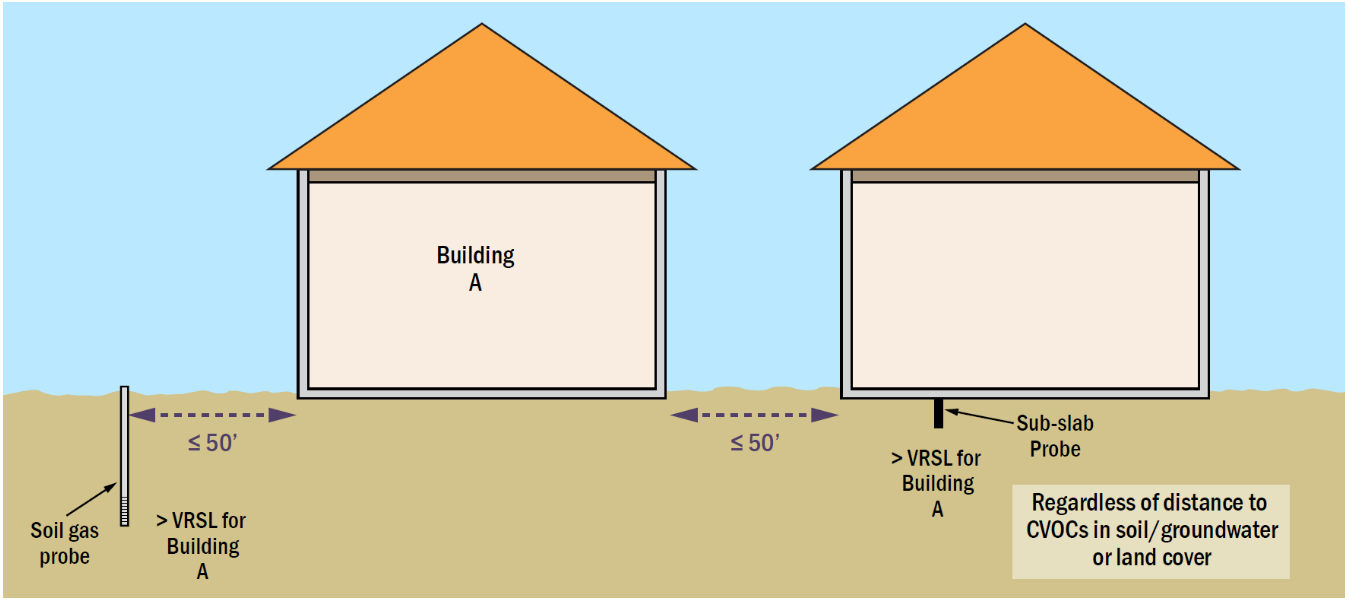
Scenario 2B. Groundwater Screening



Scenario 2C. Groundwater Screening, Physical Barrier (e.g., overhead electrical lines, underground utilities)



Scenario 2D. Preferential Pathway Screening



Scenarios 2E and 2F. Vapor Concentration Screening

The DNR recommends a VI field investigation if a building meets the guidelines below. See Notes a and b.

Scenario 2A. Unsaturated Soil Screening. CVOCs present at any concentration above the limit of quantitation (LOQ):

Within 150 feet unless the ground surface between the contamination and the building is largely permeable (i.e., open ground). See Note c.

Scenario 2B. Groundwater Screening. Overlying compound concentrations above the following:

	Compound		
	TCE	**PCE**	**Other compounds** **Use Equation 1 for C_{gw} (Note f)**
Vertical separation greater than 5 feet See Note e	5 µg/L	50 µg/L	Use default AF (0.001/0.0003)
Vertical separation less than or equal to 5 feet See Note e	0.5 µg/L	5 µg/L See Note j	Use AF = 0.01/0.003 See Note g
Groundwater contacting foundation	0.05 µg/L See Notes i and j	0.5 µg/L See Note j	Use AF = 0.1/0.03 See Notes g and j

Scenario 2C. Groundwater Screening, Physical Barrier.

See Note d.

Scenario 2D. Preferential Pathway Screening

Refer to *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649) to determine which buildings may be at risk; available at dnr.wi.gov, search "RR-649."

Scenarios 2E and 2F. Vapor Concentration Screening

Use the VRSL for the building being evaluated (e.g., Building A) in the investigation. See Note h.

Scenario 2E. Within 50 feet laterally or vertically of a soil gas sample with contaminant concentrations above the VRSL.

Scenario 2F. A building with a sub-slab vapor sample with contaminant concentrations above the sub-slab VRSL.

Figure 2 Notes:

a. The recommended screening guidelines apply to all buildings, occupied or not, and properties that do not currently have buildings. See Section 5.1 for recommendations relating to occupancy levels. Evaluate vapor conditions of new buildings constructed within these screening distances after construction to meet the requirements of Wis. Admin. Code § NR 716.11(3)(a) to define the nature, degree and extent of contamination in all affected media and the closure criteria in Wis. Admin. Code § NR 726.05(4)(a) and (e) for protection of public health. See Sections 10.4 and 10.5 for recommendations on evaluating construction, and Appendix F for recommendations on vapor mitigation for new construction.

b. Screening guidelines are conservative to include buildings where the risk of indoor air exceeding an excess lifetime cancer risk of 1-in-100,000 (1×10^{-5}), or a hazard index (HI) of 1 for non-carcinogens, is possible for protection of the most sensitive populations. In some situations, site-specific conditions may support a decision that sampling is not necessary. In other situations, the presence of multiple sources may warrant more conservative screening distances. If using screening guidelines other than those shown based on site-specific conditions, submit the data and evaluation to the DNR that demonstrates that vapor sampling is not needed at a particular building (Wis. Admin. Code § NR 716.09(2)(f) and NR 716.15(3)(h)). The decision to exclude buildings from sampling early in the investigation process may cause a delay in obtaining case closure. Consider requesting DNR technical review of the workplan (with fee) under Wis. Admin. Code ch. NR 749 if proposing alternative screening guidelines.

c. The DNR recommends a 150-foot screening distance unless the ground surface between the soil contamination and the receptor building is mostly permeable. Active or passive soil gas samples in settings with impervious surface covers may have benefit in defining nature, degree and extent of contamination. Sites primarily covered by impermeable surfaces (e.g., pavement or buildings) generally allow contaminant vapors to accumulate and migrate farther than if covered by permeable surfaces (e.g., mulch, vegetation, open ground). See Appendix A for additional information to consider when determining the appropriate screening distance. Investigation of all buildings within the screening distance may be unnecessary if an investigation of the buildings nearest to the soil source reveals vapors are not migrating and preferential pathways are not a concern.

d. If placing wells close to the building is not feasible, the DNR recommends using the highest contaminant concentration from wells within 100 feet of a building to determine contaminant concentrations in groundwater beneath the building.

e. The DNR recommends documenting vertical separation and assessing anticipated future conditions in the evaluation. Vertical separation is the distance between the lowest point of the building (e.g., crawl space, basement, foundation) and the water table. Groundwater contamination that is deep within the water column with an uncontaminated layer of groundwater above it is not likely to present a VI risk.

f. Groundwater concentrations posing a potential VI risk can be calculated from the Henry's Law constant for a contaminant, which defines partitioning into the vapor phase from groundwater at the water table:

Equation 1. Groundwater Concentrations Posing Vapor Intrusion Risk

$$C_{gw} = \frac{VAL}{H \times AF_{GW} \times 1000\ ^{L}/_{m^3}}$$

Where:
C_{gw} = Groundwater Concentration (µg/l)[6]
VAL = Vapor Action Level (µg/m^3)
H = Henry's Law constant (dimensionless)
AF_{GW} = Groundwater Attenuation Factor[7]

g. Because default AFs were not established using data from buildings where the foundation is close to a groundwater source, the DNR recommends using the higher AF (lesser dilution) listed in the figure for residential and small commercial versus the lower AF (higher dilution) listed for large commercial and industrial. See Section 9.3 for description of difference between the two categories to assist with selecting the most appropriate AF.

h. These distances are regardless of the amount of ground cover. See Table 8 for the recommended AF to use.

i. The TCE concentration 0.05 µg/L may be below the laboratory's method detection limit. The DNR recommends investigating the building for VI for any TCE concentration reported above the method detection limit.

j. Delineation of contamination in groundwater may not be required to this value (depending on the groundwater values listed in Wis. Admin. Code ch. NR 140). In such cases, DNR recommends sampling the sump water within a building, if present, to determine if water in contact with the building exceeds these recommended concentrations or use professional judgement regarding the need to place wells to assess this condition, based on known or estimated elevations of the building foundations and the water table.

[6] See *Guidance: Wisconsin Vapor Quick Look-Up Table, Indoor Air Vapor Action Levels and Vapor Risk Screening Levels* (RR-0136), available at dnr.wi.gov, search "RR-0136" for the contaminants most found at VOC sites in Wisconsin and for instructions for using the VISL Calculator for other contaminants.

[7] 0.001 residential and small commercial; 0.0003 large commercial and industrial; the use of these default AFs for groundwater may not be appropriate if natural preferential pathways (e.g., fractured bedrock) or human-made preferential pathways (e.g., sumps) are present, the water table occurs within five feet of the foundation, or a light non-aqueous phase liquid (LNAPL) exists on top of the water table (U.S. EPA 2015a).

2.5 Screening for Petroleum VOCs

Potential for Explosive Conditions
High concentrations of petroleum vapors can create an explosion risk. Explosion hazards are most often associated with a new discharge of petroleum compounds to the environment. Ethanol-blended fuel releases can also result in the generation of methane and explosive conditions. Hazardous spills responders and local fire departments can help evaluate explosion risk. Measure the Lower Explosive Limit (LEL) in soil gas and/or indoor air to evaluate an explosion hazard. Immediate or interim action is required to eliminate explosion hazard (Wis. Admin. Code ch. NR 708).

Unlike chlorinated compounds, vapors from most petroleum hydrocarbons readily biodegrade in unsaturated vadose zone soils. Because of this behavior, vapor intrusion (VI) can often be ruled out during screening if certain conditions are met.

Petroleum or petroleum products include, but are not limited to, gasoline, kerosene, fuel oil, oil sludge, oil refuse, oil mixed with other wastes, crude oil, and purified hydrocarbons that have been refined, re-refined, or otherwise processed for the purpose of being burned as a fuel or are suitable for use as a motor fuel or engine lubricant.

Sites where petroleum VOCs (PVOCs) are the primary contaminant include, but are not limited to, gasoline and diesel gas stations, heating oil underground storage tanks (USTs), refineries and bulk storage facilities, former manufactured gas plants, creosote facilities, and dry cleaners using *only* petroleum solvents. However, many of these facilities may have also used non-PVOC compounds. If present, screening for these other compounds is recommended as described in Section 6.

The screening recommendations in this appendix are based largely on information in petroleum specific VI guidance documents by ITRC and U.S. EPA.[8]

2.5.1 Applicability of Figure 3

The screening guidelines in Figure 3 can be used for PVOCs that readily degrade in the presence of oxygen. The DNR recommends Figure 3 when screening for benzene, ethylbenzene, toluene, 1,2,4-TMB, 1,3,5-TMB, *m*- & *p*-xylene, *o*-Xylene, and the semi-volatile organic compound (SVOC), naphthalene. Petroleum products contain a wide variety of other compounds, including some that are resistant to degradation; the use of screening guidelines in Figure 3 is not appropriate for recalcitrant compounds like those listed in in Section 2.5.3. Evaluate other compounds and new compounds being added to petroleum products (*e.g.*, 2,2,4-trimethyl pentane) for recalcitrance and vapor risk.

2.5.2 PVOC Screening Recommendations

Sub-slab vapor sampling is required when soil, soil gas or groundwater sampling results indicate vapor may migrate to a building (Wis. Admin. Code §§ NR 716.11(3)(a) and (5)(g)). The screening guidelines in Figure 3, along with other site-specific conditions, can be used to determine whether sub-slab sampling is needed. Provide the technical data and the evaluation to the DNR to support the screening results.

2.5.3 Exclusions to Using Figure 3

Application of the screening guidelines in Figure 3 are not appropriate when the factors below are present near a building; further evaluation of the vapor pathway is warranted.

Additives
Additives such as oxygenates (e.g., methyl tert-butyl ether (MTBE)) and lead scavengers (e.g., ethylene dibromide (EDB) and 1,2-DCA) are not considered PVOCs; unless the DNR approves an alternative approach, the DNR recommends using the screening guidelines in Section 6. (For additional

[8] ITRC 2014 and U.S. EPA 2015b.

information see Kolhatkar 2019, and Kolhatkar 2021, Hers 2021, and Chapter 10 of U.S. EPA 2015b.)

Ethanol
The presence of ethanol can inhibit the biodegradation of PVOC compounds, and methane generation from ethanol degradation may result in an increased risk of explosive conditions. The screening guidelines in Figure 3 are not applicable for releases of gasoline containing greater than 10% ethanol, including E85, denatured fuel-grade ethanol (E95), and other fuel blends greater than E10 such as E15 or E20. See MPCA 2021 for additional information related to investigating ethanol-blended fuel releases.

Excessively Dry Soils
Certain geologic materials are not biologically active enough to sufficiently degrade PVOCs to be included in the vertical separation distance. These include:

- Coarse sand and gravel with a low content of silt, clay, and organic matter, and low moisture content (less than 2% moisture content by dry weight)
- Fractured, faulted, or jointed consolidated rock
- Consolidated rock with solution channels (i.e., karst bedrock)

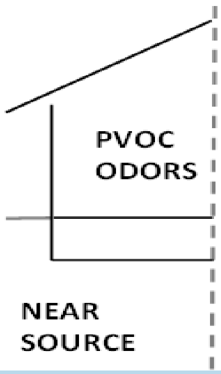
High Organic Matter Content Soils
The presence of high organic content (greater than 4% by dry weight) can exert a high oxygen demand and inhibit aerobic degradation of PVOCs in soils such as peat, bay muds, wetland and delta soils.

Impervious Surfaces
Buildings greater than 66 feet on the shortest side[9] or buildings surrounded by extensive impermeable surface coverings can have an oxygen or moisture shadow that results in less suitable conditions for biodegradation.

Ongoing Release/Expanding Dissolved Plume or Migrating NAPL
An ongoing release of petroleum product, an expanding dissolved groundwater contaminant plume, or migrating non-aqueous phase liquid (NAPL) from an existing source will prevent accurate definition of the lateral inclusion zone.

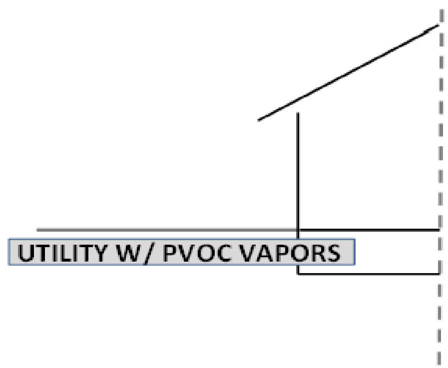
[9] U.S. EPA 2013.

Figure 3. Scenarios Where Vapor Sampling at a Building is Recommended – PVOCs



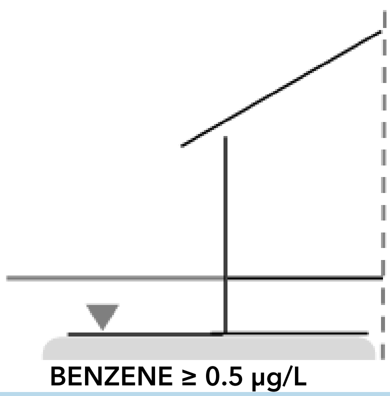
Scenario 3A

Petroleum odors are present in the building near petroleum source area.[c]



Scenario 3B

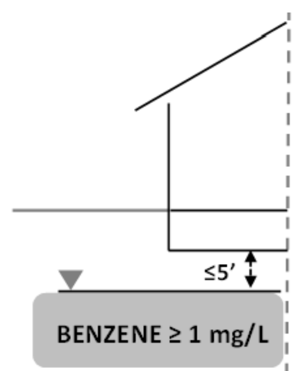
Petroleum vapors are present in utilities that transect a petroleum source area. See RR-649 for recommendations.[c]



Scenario 3C

Contaminated groundwater contacts the building foundation: Groundwater with a benzene concentration ≥ 0.5 μg/L has entered the building or is in contact with the building foundation.[c]

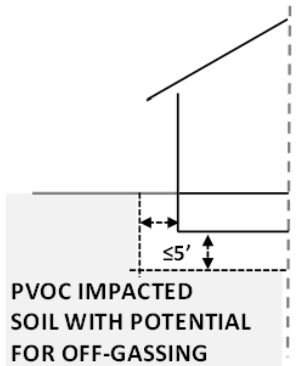
μg/L = micrograms per liter



Scenario 3D

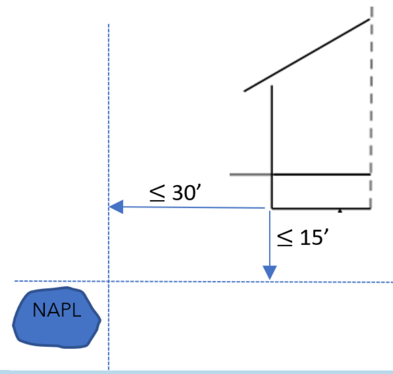
Contaminated groundwater below the building foundation: ≤ 5 feet of vertical[b] separation between the building foundation and groundwater with benzene ≥ 1 mg/L.

mg/L = milligrams per liter



Scenario 3E

≤ 5 feet of (vertical[b] or horizontal) separation between the building foundation and petroleum contaminated soil with the potential for off-gassing, including light end distillates (e.g., gasoline).



Scenario 3F

Building ≤ 30 feet horizontally and has ≤ 15 feet vertical[b] separation from non-aqueous phase liquid (NAPL). NAPL Indicators:

- Free or residual phase NAPL
- Laser induced fluorescence (LIF) response in light NAPL (LNAPL) range
- Benzene > 5 mg/L in groundwater or 10 mg/kg in soil
- Naphthalene > 5 mg/kg in soil (but NAPL may exist at lower concentrations).
- Benzene, toluene, ethylbenzene, xylenes (BTEX) > 20 mg/L in groundwater or 10 mg/kg in soil (performed by adding the concentrations of individual compounds).

mg/kg = milligrams per kilogram

Figure 3 Notes:

a. Indoor air sampling paired with sub-slab vapor sampling is recommended in all scenarios except when the contaminant of concern (COC) is in use in non-residential settings. See Section 8.5.3 for additional recommendations on indoor air sampling.
b. Vertical separation is the distance between the lowest point of building (e.g., crawl space, basement, foundation) and the contaminant.
c. In these scenarios, collection of a sub-slab vapor sample may not be sufficient to characterize the risk to occupants (when odors are present in indoor air), may not be indicative of the risk to indoor air (when utilities may be a pathway for vapors into the building), and may be difficult (when groundwater contacts the foundation. Evaluation of VI will rely more heavily on indoor air data and other lines of evidence (LOE)).

2.5.4 Additional Considerations When Investigating PVOCs

- The DNR recommends collecting the following site information and developing a VI conceptual site model (CSM) (see Section 5)
    - Type and age of petroleum release
    - Presence and location of NAPL
- Presence of precluding factors (see Section 2.5.3), including:
    - non-PVOC additives
    - ethanol blended fuels
    - excessively dry, high organic matter soils or natural preferential pathways
    - buildings in excess of 66 feet on the shortest side or surrounded by extensive impermeable surfaces,
    - on-going release, expanding plume, migrating NAPL.
- Figure 3 or alternative method may be used to determine if sub-slab and indoor air should be sampled. Document basis and conclusions if recommending no VI sampling (Wis. Admin. Code § NR 716.11 (5)(g)).

2.6 Building Sampling Decisions

Figure 4 may be used when deciding when and where to perform initial sampling at a building, and Table 2 to make building specific decisions on additional investigation, and immediate and interim actions.

Figure 4. Initial Building Sampling and Evaluation for Vapor Intrusion Risk

Initial Building Sampling and Evaluation of VI Risk

Evaluate the need for standard vapor sampling or installing a VMS during sampling (see Section 7.2)

Combined investigation and mitigation Proposed?

Yes

Following **DNR approval** of a plan to install a VMS during sampling, collect sub-slab vapor and indoor air, then install mitigation system (prior to receipt of sample results).

Mitigation systems must be designed, installed, performance verified, and a long-term OM&M plan completed in accordance with Wis. Admin. Code §§ NR 708.05, NR 708.11 and ch. NR 724 (see Appendix F)

Provide **stewardship** of mitigation systems until case closure (see Section 12 and Wis. Admin. Code ch. NR 724).

The DNR may assign **COs** at time of the interim action, remedial action and case closure (see Sections 12 and 13, Wis. Stat. §292.12(2) and Wis. Admin. Code chs. NR 724 and NR 726).

No

Building Sampling

When an occupied building falls within the screening distance for that chemical, in most cases the DNR recommends vapor sampling at the building, including sub-slab vapors and indoor air, except for buildings at which the COC is still in use (Wis. Admin. Code §§ NR 716.11(5)(g) and (h)). If TCE is the COC and women who are or may become pregnant are present, notify the DNR. The DNR may involve the DHS and the local health department to assist with risk communications.

Standard Vapor Sampling – Initial Sampling Event

Sub-slab vapor sampling recommendations

- **Residential single family:** 1 or 2 samples per 1,500 ft^2
- **All other buildings:** building-specific decision based on CSM

Indoor air sampling recommendations

- **Real time sampling:** recommended when preferential pathways are suspected, for buildings larger than 25,000 ft^2, for variable sub-slab vapor concentrations, for complicated air handling systems to select follow-up canister or passive sampling locations, or to guide RRM.
- **Relation of indoor air sampling to sub-slab vapor sampling:** recommended to collect indoor air samples within 24 to 48 hours of sub-slab vapor sampling. For complex commercial and industrial buildings, an initial sub-slab vapor sampling event to guide selection of indoor air sample locations may be acceptable (unless TCE and women who are or may become pregnant are present).
- **Sample duration:** Typically 8 hours for non-residential settings and 24 hours for residential settings to evaluate potential for acute risk when appropriate. Long duration sampling could also be initiated.
- **Ambient/outdoor air:** representative, upwind outdoor air samples should be collected whenever indoor air is sampled.
- **Sample locations for residential single family:** Minimum of 2 sample location in lowest level when sub-slab VI is the primary concern (versus preferential pathway). Recommendations for upper levels is building-specific based on the CSM.
- **Sample locations for all other buildings:** building-specific decision based on CSM.

Notification of sampling results

Notify the DNR, property owner(s) and occupant(s) of results within 10 business days of receipt (Wis. Admin. Code § NR 716.14(2)). An accelerated notification timeline is appropriate when TCE and women who are or may become pregnant are present.

- Evaluate vapor sampling results
- Plan subsequent sampling
- Perform immediate and/or interim actions at occupied buildings (see Table 2 and Wis. Admin. Code ch. NR 708)

Initial Building Sampling Event Timeline Recommendations

Accelerated

Within days (not weeks) of a building "screening in" if TCE and women who are or may become pregnant are present. Women who are or may become pregnant should be consulted about the potential TCE developmental toxicity risk so they may make informed decisions in terms of staying in the building during the timeframe of the indoor air assessment.

Within days (not weeks) of a building "screening in" if concentrations beyond the building envelope are >3X the VRSL (NC) or >10X the VRSL (C).

Standard

Within 1 to 2 months of submitting the workplan in most situations. The DNR recommends a more accelerated schedule if concentrations beyond the building envelope suggest high concentrations may be present in indoor air.

Laboratory Turnaround Time (TAT)

24 to 72 hours laboratory TAT is recommended for indoor air samples when TCE and women who are or may become pregnant are present or the concentrations beyond the building envelope are >3X the VRSL (NC) or >10X the VRSL (C).

Table 2. Building Decision Recommendations

Decision Matrix 1: Compounds Other Than TCE

<table>
<tr><th rowspan="6">Sub-slab Vapor Concentration</th><th colspan="5">Indoor Air Concentration</th></tr>
<tr><th>Compounds Other than TCE</th><th>ND to < 50% VAL</th><th>50% VAL to < VAL</th><th>≥ VAL</th><th>≥ 3X VAL NC or
≥ 10X VAL C
* All Situations</th></tr>
<tr><td>ND to < 50% VRSL</td><td>Perform recommended number of sampling events. No additional VI field investigation needed if sampling is complete (little to no risk).[a]</td><td rowspan="2">Perform recommended number of vapor sampling events and evaluate data (close to VAL or VRSL and consider all LOE).[d]</td><td colspan="2" rowspan="2">Identify source and/or mitigate.[b]</td></tr>
<tr><td>50% VRSL to < VRSL</td><td></td></tr>
<tr><td>≥ VRSL</td><td colspan="2">Mitigate within 4 to 8 weeks in residential settings.[c] See Note c for other buildings.</td><td colspan="2" rowspan="2">Mitigate within 4 weeks.[c]</td></tr>
<tr><td>≥ 3X VRSL NC or
≥ 10X VRSL C</td><td colspan="2">Mitigate within 4 to 8 weeks.</td></tr>
</table>

Decision Matrix 2: TCE

<table>
<tr><th rowspan="6">Sub-slab Vapor Concentration</th><th colspan="5">Indoor Air Concentration</th></tr>
<tr><th>TCE</th><th>ND to < 25% VAL</th><th>25% VAL to < VAL</th><th>≥ VAL
* If women who are or may become pregnant present</th><th>≥ 3X VAL
* All Situations</th></tr>
<tr><td>ND to
< 25% VRSL</td><td>Perform recommended number of sampling events. No additional VI field investigation needed if sampling is complete (little to no risk).[a]</td><td rowspan="2">Perform recommended number of vapor sampling events and evaluate data (close to VAL or VRSL and consider all LOE).[d]</td><td colspan="2" rowspan="2">Identify source and/or mitigate.[b]</td></tr>
<tr><td>25% VRSL to < VRSL</td><td></td></tr>
<tr><td>≥ VRSL</td><td>Mitigate within 4 to 8 weeks in residential settings.[c] See Note c for other buildings.</td><td rowspan="2">Mitigate within 4 to 8 weeks.[c]
• Consult women who are or may become pregnant about TCE risks.
• Perform weekly interim indoor air monitoring to ensure exposure is not occurring.</td><td colspan="2" rowspan="2">Mitigate within 2 weeks.
Initiate RRM within 48 hours if women who are or may become pregnant are present.[c]</td></tr>
<tr><td>≥ 3X VRSL</td><td></td></tr>
</table>

Key

C	Carcinogen for Inhalation Pathway
LOE	Lines of Evidence
NC	Non-Carcinogen for Inhalation Pathway
ND	Not Detected
RRM	Rapid Response Measures (see Section F2.2.1 for more information)
VAL	Vapor action level
VRSL	Vapor Risk Screening Level

Involve the DNR and DHS/Local Health. The DNR recommends contacting the DNR promptly by phone or email. The DNR recommends promptly contacting the DNR project manager whenever indoor air concentrations are over a VAL to help evaluate the risk from exposure to vapors, the potential need for immediate action and to assist with risk communication, as needed. The DNR may consult with the DHS, who may inform local health departments and establish a lead health agency. The DNR may also recommend involving the DHS and/or local health when sub-slab vapor concentrations suggest a potential acute risk; however, this will typically begin as a site-specific discussion between the DNR project manager and RP.

*

Immediate Action. These situations warrant an immediate action under Wis. Admin. Code ch. NR 708 to interrupt the vapor pathway while the site undergoes additional monitoring, interim actions and/or remediation. Vapor mitigation may be used to reduce levels to below VAL as part of an immediate action; however, use periodic indoor air testing to confirm that levels remain below VAL for occupancy. If women who are or may become pregnant occupy the dwelling, the DNR recommends sampling indoor air after implementing actions with a 24 to 72-hour lab turnaround time to meet the requirements in Wis. Admin. Code §§ NR 708.05 and NR 708.11. The DNR recommends informing women who are or may become pregnant about the potential fetal developmental toxicity risk related to TCE so women who are or may become pregnant can make informed decisions regarding occupancy of the dwelling during the timeframe of the indoor air assessment.

Emergency Action (Wis. Admin. Code § NR 708.05(2)). Actions may be needed to protect human health, depending upon the extent by which the concentration exceeds the VAL. The DNR recommends consulting the local health officer regarding potential abatement orders, placarding and temporary relocation of occupants under Wis. Stat. ch. 254. In extreme situations, the DHS and/or local health departments may declare that a situation constitutes a "human health hazard" under Wis. Stat. § 254.59 and may relocate occupants of the building until indoor air concentrations decline to less than the VAL. Contaminants such as petroleum vapors from a recent discharge, ethanol blended fuel, or methane may pose an explosion hazard.

Notes:

a. Perform the recommended number of sampling events; no additional VI field investigation needed if sampling is complete. If all data is less than the criteria shown, the DNR recommends continuing the sampling at the recommended schedule in Note d. In situations where concentration data from the building collected during the assessment period indicate little to no risk from VI, the VI field investigation is complete and no additional actions are recommended to address human exposures. However, all LOE should be evaluated before deciding that no additional VI field investigation is necessary for the building. See Section A3.

b. Identify source. Indoor air concentrations above the VAL combined with sub-slab vapor concentrations below the VRSL indicates that there may be an indoor air source for the contaminant (see Section 9.1 for more information on background vapor sources). However, a few sub-slab vapor sample results may not be representative of actual sub-slab vapor concentrations. Sub-slab vapor concentrations that are near to the VRSL indicate a VI source of contamination. The DNR recommends considering other information, such as the proximity of the building to the source, and source strength, and whether sub-slab vapor concentrations make sense in the context of other data.

The DNR recommends taking reasonable and practical actions to identify the source(s) affecting indoor air quality. This will likely include attempting to locate an indoor air source (a hand-held meter may assist with this), removing it, and then re-sampling indoor air. Indoor air concentrations above the VAL may also indicate contaminant contribution from a preferential pathway. Further evaluation of preferential pathways may be necessary[10]. Manipulating building pressure may also be useful (see Section 8.5.3). However, if TCE is the COC and women who are or may become pregnant are occupants, or concentrations are much greater than the VAL for all occupants, the DNR recommends interim measures (see Section F2.1) to minimize possible VI exposure while the investigation proceeds (Wis. Admin. Code § NR 708.11). The DHS and local health officials can assist with risk communication and local health authority during this process. The DNR may recommend mitigation if the source cannot be determined after a reasonable attempt to locate it, and VI cannot be ruled out. It is important to identify the source of the contaminant. Otherwise, mitigation measures may be ineffective in reducing indoor air concentrations. If an indoor air source is found that explains the VAL, the DNR recommends completing additional sampling rounds.

c. Mitigation. Once the need to mitigate is identified, the entire building footprint should usually be mitigated. For structures larger than 25,000 square feet, additional sub-slab vapor sampling may show that the extent of contamination is limited. See Appendix F for additional mitigation information.

Mitigation timeframes. Recommendations for time frames within which mitigation should be implemented are shown in the table. These are based on contaminant type and concentrations and consider recommendations from the DHS (See Appendix H). In general, the recommendation is to install mitigation systems at occupied buildings in residential settings within 4 to 8 weeks (less in some situations). For other types of buildings, the timing of mitigation should consider site factors, such as whether a remedial action will be undertaken that will likely reduce contaminant concentrations soon if proposing a longer time frame for implementation. See Section 10 and Appendix F for additional information on response actions.

Perform weekly interim indoor air monitoring. Although indoor air concentrations were below the VAL, the presence of contaminant(s) were indicated by sub-slab vapor concentrations above the VRSL. Unless a VMS or interim measures such as an indoor air treatment unit are installed within a few days (these are the preferred actions), the DNR recommends additional weekly indoor air sampling to ensure concentrations are not above the VAL. A real-time portable sampling device could be deployed to monitor indoor air concentrations until mitigation is performed.

RRM. See Section F2.2.1

[10] See *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649) for more information; available at dnr.wi.gov, search "RR-649."

d. Perform recommended number of vapor sampling events and evaluate data. The results from each vapor sampling event should be evaluated to determine whether there is a need for immediate and/or interim action, or to continue with additional vapor sampling events and how soon those should be performed; see Section 9 for more information on evaluation. If all concentrations are less than the VRSL and VAL, the DNR recommends continuing to sample at the recommended schedule shown below. However, when sub-slab vapor and/or indoor air contaminant concentrations approach the levels of the VRSL and VAL, and considering the variable nature of vapor concentrations, additional evaluation of the effectiveness of the current sampling program to assess indoor air exposures is warranted.

After the initial sampling event which includes collection of the required sub-slab vapor samples, particularly where TCE is a contaminant, a decision to install a VMS while sampling is still being conducted may be considered. See Section 7.2 for more information on installing a VMS during sampling.

After completion of the minimum recommended vapor sampling below, all LOE and the factors listed in Appendix A should be considered to decide whether:

- VI is not occurring in the present and not likely in the future,
- additional vapor sampling is needed to rule out VI, or
- mitigation is warranted based on LOE other than current sub-slab vapor results.

Follow-up Sampling Event Recommendations (after the initial sampling recommended in Figure 4 is complete).

Contaminants other than TCE

Additional vapor sampling events are recommended during the winter assessment period and any other period of expected RME (both explained further below).

- Indoor air - Two events during the winter assessment period.
- Sub-slab vapor samples - Events concurrent with indoor air.

The winter assessment period is defined in this document as the period between December 1 and March 31 when frost conditions with closed doors and windows and active heating are more likely to create maximum indoor air concentrations.

TCE

Timing of follow-up vapor sampling depends on the conditions during initial sampling, primarily occupancy, concentrations, and season. Compared to a COC that only poses a chronic concern, additional sampling events are needed to evaluate the risk from TCE which can occur during relatively short durations of exposure.

Acute Risk Concern. In the following situation, the DNR recommends a second longer duration (typically 10 days or longer) indoor air sampling event be performed within 30 days. This is a check on the initial results without waiting several months for the winter assessment period.

- initial sampling event occurred from mid-April to mid-September,
- women who are or may become pregnant are occupants, and
- concentrations of the COC were above 25% of the VAL or VRSL for TCE during the first round

Indoor Air. The DNR recommends sampling a minimum of three long-duration (typically 10 days or longer) rounds, one during each of the following periods:

- Indoor Air:
  - late fall/early winter (e.g., mid-November to December),
  - mid-winter (e.g., January-February), and
  - late winter/early spring (e.g., March to mid-April).

  Although mid-November to December 1st, and March 31st to mid-April are beyond the defined winter assessment period, this allows some flexibility when all sampling events are planned over just a few months (e.g., during a single winter).

- Sub-slab vapor samples: Two events concurrent with an indoor air event.

An alternative to performing three 10-day discrete sampling events that would involve six visits to a property could entail placing samplers for 28-day consecutive durations. This could be accomplished with four site visits during the winter assessment period. For example:

1. deploy passive sampler #1 in December
2. pick up #1 and deploy #2 in January
3. pick up #2 and deploy #3 in February
4. pick up #3 in March.

Notes

Recommended sample duration

- Indoor air: 10 days or longer. This could include consecutive durations of up to 28 days each.
- Sub-slab vapor: Concurrent with indoor air.
- Shorter durations: Sampling using only short-duration events (e.g., 8 or 24 hours) will likely require many more rounds of sampling to determine the impact VI currently has to an occupied building. (See Section 8.5.3 and Appendix A.)

Additional events

For some buildings, RME may occur during times of the year outside of the winter assessment period. Additional sampling events are recommended for these buildings. The most common situation is:

- When the water table rises to contact the building foundation.
- After a significant drop in groundwater levels.
- Where periodic/seasonal building operations enhance VI.

Building pressure cycling (BPC)

If BPC is used, one sampling period for indoor air may be sufficient if the sampling was completed using procedures appropriate for the building and setting. See BPC in Section 8.5.3.

3 Is Trichloroethylene Present?

Contamination that includes TCE is a concern due to its potential for acute (short-term) human health risks at relatively low concentrations in air (see DHS 2017 in Appendix H). TCE is a chlorinated solvent and common degreaser and is also a breakdown product of PCE (aka, perc), a historically common dry cleaning chemical.

A single exposure to TCE by women who are or may become pregnant early during pregnancy poses a risk to fetal heart development, in addition to other developmental effects (see DHS 2021 in Appendix H). A single exposure is defined as an 8-hour or 24-hour period depending on whether the exposure is in a work setting or a residential setting (see DHS 2022 in Appendix H). TCE and other contaminants may pose an acute health risk to all persons if present at high enough concentrations in indoor air[11].

Screening (discussed in Section 2.3, Element 2) for VI must be conducted at every contaminated site in Wisconsin per Wis. Admin. Code § NR 716.11(5)(a). The DNR recommends prioritizing screening for VI when TCE is present and then promptly sampling. Simultaneous immediate action (Wis. Admin. Code § NR 708.05) and interim action (Wis. Admin. Code § NR 708.11) may be appropriate. Notify the DNR project manager along with state and local health officials, who may be able to assist with access, data evaluation and risk communications.

TCE can pose a health risk to humans during very short periods of time and at very low concentrations, therefore, investigation of TCE sites may be more rigorous and risk decisions more conservative. Even if women who are or may become pregnant or other sensitive populations do not currently occupy a building, decisions should account for this possibility in the future.

[11] Visit dnr.wi.gov, search "vapor" for additional information on the acute health risks from TCE and other contaminants.

4 Public Outreach, Community Engagement and Property Access

The primary goal of a VI field investigation is to ensure current and future building occupants are protected from exposure to harmful contaminant vapors that may cause acute or chronic health effects. In addition to notifying occupants on the source property, an RP may need to conduct field investigation and mitigation of the VI pathway on off-site properties the RP does not own or maintain. Early and effective communication with potentially affected owners and occupants is an important part of protecting human health.

4.1 Required Notifications

Situations that require notification to the public are summarized in Table 3, below.

Table 3. Required Notifications to the Public

WIS. ADMIN. CODE	DESCRIPTION
§ NR 714.07	Provide introductory information about the contamination, response actions, and persons to contact to: • owners and occupants of properties with potential VI; and • other neighboring properties, depending on the level of public concern.
§ NR 716.14	Provide sampling results within 10 business days of receipt to the DNR and any owners and occupants of properties where samples were collected. The DNR may approve a different notification schedule on a case-by-case basis. *Note:* Results that indicate potential acute exposure situations may require immediate response under Wis. Admin. Code § NR 708.05. The DNR recommends providing results to all parties including the DNR project manager as soon as possible, preferably by phone or email, if any of the following occur: • TCE exceeds the VAL in indoor air and women who are or may become pregnant are present; • a non-carcinogen for inhalation toxicity (e.g., PCE) exceeds three times the VAL; or • a carcinogen for inhalation toxicity (e.g., naphthalene) exceeds ten times the VAL. The DNR recommends engaging the DHS and/or local health to assist with risk evaluation and communication. See Table 2.
§ NR 725.05	Provide information on OM&M required to prevent VI when residual contamination poses a VI risk, and one or more of the COs listed in Section 13 will be assigned to the property.

4.2 Special Considerations Regarding Vapor Intrusion Investigations, Mitigation and Long-Term Stewardship

Wis. Admin. Code § NR 716.11(3)(a) requires an RP to determine the nature, degree and extent of environmental contamination in all affected media, including soil gas, indoor air and air within conduits. Wis. Admin. Code ch. NR 708 requires the RP to conduct immediate or interim actions to protect public health from a hazardous substance discharge or environmental contamination when certain conditions are met (Wis. Admin. Code §§ 708.05 and 708.11). The RP must follow the contamination off-site and protect humans from exposure to harmful vapors (Wis. Admin. Code § NR 716.11(4)).

VI field investigations and mitigation efforts may differ from other environmental investigations and cleanups in important ways:

a. VI field investigations may require repeated entry into homes and businesses, causing disruption to

occupants.
b. VI may be a relatively new concept for the public compared to contaminant transport within soil and groundwater.
c. VI includes involvement of multiple disciplines (e.g., soil gas experts, heating, ventilation, and air conditioning (HVAC) and plumbing professionals).
d. Mitigation efforts are typically intended to be maintained indefinitely to protect occupants from contamination.

Investigations for smaller discharges to the environment may be limited to the site and one or two adjacent properties. However, investigations for larger discharges could involve 10 or more off-site properties that are not controlled by the RP. **Outreach, engagement and coordination with the off-site owners and occupants to adequately assess, mitigate and perform OM&M activities requires time and effort to earn and maintain trust, address concerns, and gain access.** Successful VI field investigation and cleanup depend on partnerships between the RP[12], the DNR, the DHS, the local health department and other stakeholders (e.g., community organizations, local leaders).

The DNR recommends proactively addressing common questions and concerns of affected property owners and tenants to streamline the investigation and any interim actions needed. During the investigation process, property owners may have concerns about health and entry into their space. Establishing comfort and trust early in the process may help the VI field investigation to proceed more efficiently and effectively.

The DNR recommends creating a public outreach and a community engagement plan and routinely reviewing and revising this plan as relationships with the public and other stakeholders evolve[13].

Concerns from the Public
Common questions and concerns from the public during the investigation stage for VI include:
- Why is VI being investigated now, after all this time?
- I feel fine or I don't smell anything – how is this a problem?
- How does this affect my health?
- Who is paying for this?
- Will the sub-slab port installation create a water problem?
- I am uncomfortable with workers entering my home/interrupting customers.
- How long will this disruption last?

During the mitigation stage, questions and concerns may include:
- What does this do to my property value?
- Who is paying for this?
- What will mitigation look like?
- Will it be noisy?
- I am uncomfortable with workers entering my home/interrupting customers.
- How long will this disruption last?
- Who is responsible to maintain this?
- How long does the mitigation have to stay in place?

4.3 Community Outreach Tools

Members of the public and potentially affected parties may not be familiar with VI concepts and have diverse perspectives and concerns. Receiving information about VI or requests for access to buildings may raise concerns about health as well as disruptions to life, businesses, customers, and occupants. The DNR recommends giving affected parties a reasonable amount of time to process new information. Tailor communication approaches and methods to meet the needs of the parties involved.

Engage with the DNR Early
When immediate or interim actions are needed, the DNR recommends contacting the DNR project manager as early as possible. The DNR will engage the DHS and local health. See Table 2.

The DNR has a variety of resources such as template letters, DNR factsheets, videos, and DHS health-related tools to assist RPs with outreach to affected and potentially affected property owners. These resources are available at dnr.wi.gov, search "vapor" and include:

[12] Including any representatives of the RP.
[13] See the Interstate Technology Regulatory Council (ITRC) website for more information on public outreach during VI investigation and mitigation; go to itrcweb.org and search "vapor intrusion" and "community engagement."

- *Vapor Intrusion Investigation – Information Sheet for Neighbors* (RR-067) **-** an informational cover sheet for neighbors (also available in the Spanish language).
- *Template Letter: Introduction of Vapor Intrusion Issue to Neighborhood* (RR-958) - a template letter for introduction of VI issues to a neighborhood.

The resources above may help individuals understand:

a. the requirements for the RP to investigate and mitigate the vapor pathway,
b. the reasons why their involvement is necessary for their own health, and
c. the language and mechanics of VI field investigation and mitigation.

Vapor Intrusion 101 Video Available
Share the DNR's *Vapor Intrusion 101* video to introduce the concept of vapor intrusion to the public. Available at dnr.wi.gov by searching "vapor."

4.4 Access: Best Efforts

Engaging potentially affected parties, gaining access permission for a VI field investigation, and maintaining trust takes time and effort throughout the investigation. Challenges with access permission may arise (typically at the investigation phase). Gaining access permission for immediate and interim actions may require additional efforts.

The DNR recommends talking directly to property owners to gain access permission to off-site properties during an on-going investigation. Communication approaches may include phone calls, property visits and in-person meetings. Communication may be conducted in collaboration with the DHS, local health officials and other partners. Repeated property visits may be helpful; this also gives individuals time to process the information.

Use best efforts to gain access permission and work cooperatively with potentially affected parties. Best efforts may require several different approaches and attempts to contact and inform property owners and occupants. To demonstrate best efforts, the DNR recommends at least two written attempts to gain access to a building in addition to initial personal contact attempts; provide the DNR with a summary and documentation of all contact attempts. The DNR recommends keeping certified mail receipts for any letters sent.

4.5 When Access is Denied

When an off-site property owner denies access or does not respond to the RP's best efforts, notify the DNR and provide the supporting documentation. The documentation will be tracked in the Bureau for Remediation and Redevelopment Tracking System (BRRTS). The DNR project manager may work with the DHS and the local health department for additional support.

The DNR may also send a final letter to the property owner to request access. The letter informs property owners that denial of access could leave them responsible for the investigation, cleanup, and/or mitigation of contamination on their property (as the property owner may not qualify for the off-site property exemption under Wis. Stat. § 292.13), and that denial of access will be recorded in the case file for the contaminated site. The DNR will track the final access request letter in BRRTS and evaluate whether an RP letter will be issued to the off-site property owner.

The DNR will also evaluate whether the situation justifies obtaining a special inspection warrant for the off-site property on a case-by-case basis, depending on the occupancy, site conditions, and potential level of risk to occupants at the off-site property.

When the RP needs to conduct VI field investigation or mitigation and cannot gain permission for access to a property following best efforts, the DNR project manager posts the documentation of the efforts in BRRTS. This step serves as a record of the effort and communications with the off-site owner and allows the RP to move forward with any other work needed for case closure.

Prior to approving a case closure request, the DNR may revisit the efforts taken to obtain access and any documented denials for access. If the off-site conditions change before closure is approved, then case closure approval under Wis. Admin. Code § NR 726.13 may require additional efforts by the RP to gain access to the off-site property. The more time that passes before closure, the more likely it is that there will be a change in conditions to an off-site property. New conditions that prompt need for additional efforts to gain access may include:

- Changes in occupancy;
- Changes in ownership; and
- Changes in the level of potential risk based on new site information.

To avoid unnecessary delays in the closure review process, proactive discussion of changes is recommended with the DNR.

5 Scoping and Development of a Conceptual Site Model

5.1 Field Investigations for Vapor

Wis. Admin. Code § NR 716.11 specifies the requirements for a field investigation. For the vapor pathway, the goal is to evaluate the potential impact on receptors according to location-specific situations, described below.

5.1.1 Existing Occupied Buildings

In occupied buildings, the priority is identifying whether current occupants are at risk from VI. If the RP cannot rule out the possibility of VI by applying screening guidelines, the field investigation must include:

- **Sub-slab Sampling.** Determines the presence and concentration of vapors below occupied buildings (Wis. Admin. Code § NR 716.11(5)(g)); and
- **Indoor Air Sampling.** Determines the impact VI has on occupied buildings (Wis. Admin. Code § NR 716.11(5)(h)).

5.1.2 Existing Unoccupied or Infrequently Occupied Buildings

Buildings designed for occupation are sometimes unoccupied during the investigation, such as an abandoned manufacturing facility. Regardless of occupancy status, the investigation must comply with the requirements of Wis. Admin. Code § NR 716.11(3)(a), which states that the RP must determine the nature, degree, and extent of the hazardous substance discharge or environmental pollution in all affected media. Meeting this requirement requires expanding the field investigation to conduits where vapors may migrate, and vapors that may migrate beneath the foundations of buildings (Wis. Admin. Code § NR 716.11(5)(a)). Defining the extent of contamination in all affected media helps determine which COs may be protective for potential future occupants and may assist future property owners and developers with planning and risk decisions.

Some buildings are infrequently occupied and/or have a very limited number of occupants such as a storage building which one or more workers may visit once per week to load and unload materials. Buildings that are infrequently or scarcely occupied are still subject to the requirements of Wis. Admin. Code §§ NR 716.11(5)(g) and (h); short duration exposures to some contaminants can pose a health risk. The level of occupancy, building use and COCs are factors in determining whether immediate or interim actions are warranted under Wis. Admin. Code §§ NR 708.05 and NR 708.11.

5.1.3 Future Buildings

New buildings, building expansions or utilities near or through contaminant sources may result in VI exposures to occupants. The site investigation must delineate the extent of vapors, regardless of whether buildings exist on a property (Wis. Admin. Code § NR 716.11(3)(a)) at the time of the investigation. Monitor anticipated land use changes during the investigation and cleanup. If a new building or development activity is anticipated on or within the vapor screening distances of a contaminated site prior to closure, the site investigation may need to include new potential receptors or pathways (Wis. Admin. Code § NR 716.11(5)(a)). As conditions of site closure, the DNR may require the RP to take protective measures to eliminate or control VI into a future building (Wis. Admin. Code § NR 726.15(2)(L)) or an existing building with low or no current occupancy or future modifications to existing buildings (Wis. Admin. Code § NR 726.15(2)(m)). See Section 10.4 regarding new construction on contaminated sites.

Considerations for Redevelopment of Industrial Buildings
Industrial buildings with residual contamination may be redeveloped for commercial and residential use. Addressing the potential for VI necessitates careful planning. Contacting DNR staff in the early stages of project planning, before any groundbreaking begins, is recommended. DNR recommends contacting the local municipality for local redevelopment requirements and considerations such as occupancy permitting.

Occupancy of the vacant building soon after renovation may be desired. The DNR recommends comprehensive indoor air sampling after renovation but prior to occupancy. It is not possible to verify indoor air quality until the building renovation is complete and all mechanical systems are fully operational. There have been instances where a building could not be occupied due to high contaminant concentrations in indoor air that only became known following completion of the renovation. In addition, local governments have required relocation of residents when high contaminant concentrations were discovered following occupancy.

At buildings with a history of solvent use the RP may need to evaluate off-gassing from contaminated building material points in addition to assessing VI through the foundation, conduits and other preferential points of entry.

Using conservative assumptions and strategies during redevelopment, such as designing the VMS to cover the entire building footprint, sealing the foundation and penetrations, hot spot soil removal, replacement of contaminated foundation materials, using tracer gases to evaluate vapor pathways, interim vapor sampling within interior spaces at various stages of development, and BPC may help avoid unnecessary delays in the final stages of a project.

5.2 Scoping and Creating a Conceptual Site Model

Site investigation scoping ensures that the field investigation is appropriate for the complexity of the site (Wis. Admin. Code § NR 716.07). Table 1 lists the elements that typically affect vapor movement or risk from VI, and Appendix A discusses the elements in greater detail. The DNR recommends using preliminary information regarding these and other relevant elements to develop a conceptual site model (CSM) for VI. A detailed evaluation of all these elements is not necessary for every site or building; however, if LOE conflict, the DNR recommends performing a more thorough evaluation of elements that may explain the disparity (see Section A3 for more information on LOE). An example of a disparity is when indoor air concentrations are high and sub-slab vapor concentrations are low, or sub-slab vapor concentrations are low at a building overlying a groundwater plume with very high concentrations in shallow groundwater.

The initial CSM and building screening (see Sections 2.4, 2.5, and 6) informs where to conduct field investigation activities. The CSM should be re-evaluated whenever new information is obtained pertinent to the vapor pathway. The DNR recommends portraying the CSM for VI in drawings and/or cross-sections and updating these items in reports as the site investigation proceeds.

In addition to detailed figures that present environmental data, the DNR recommends producing and updating a more general figure to quickly communicate the status of the VI field investigation (i.e., identifying which buildings fall within screening distances and the respective status of access, sampling, and mitigation); Figure 5 provides an optional format.

5.2.1 CSM Boundary

The boundary of the CSM for the vapor pathway is initially based on known areas of contamination, the distance that vapors from different chemicals typically migrate in the vapor phase (see Sections 2.4, 2.5 and 6) and potential receptors.

It is recommended that the initial CSM boundary includes all buildings within the screening distances described in Figure 2 for CVOCs or Figure 3 for PVOCs; however, if sampling reveals high levels of CVOCs (particularly TCE) and the extent of contamination at the water table is uncertain, the DNR recommends sampling buildings for vapor (particularly residential) in the downgradient direction beyond those that would initially screen in, rather than waiting to install additional wells to define the extent of groundwater contamination. This practice may identify and address acute exposures more quickly. Adjust the CSM boundary when new data or information is obtained.

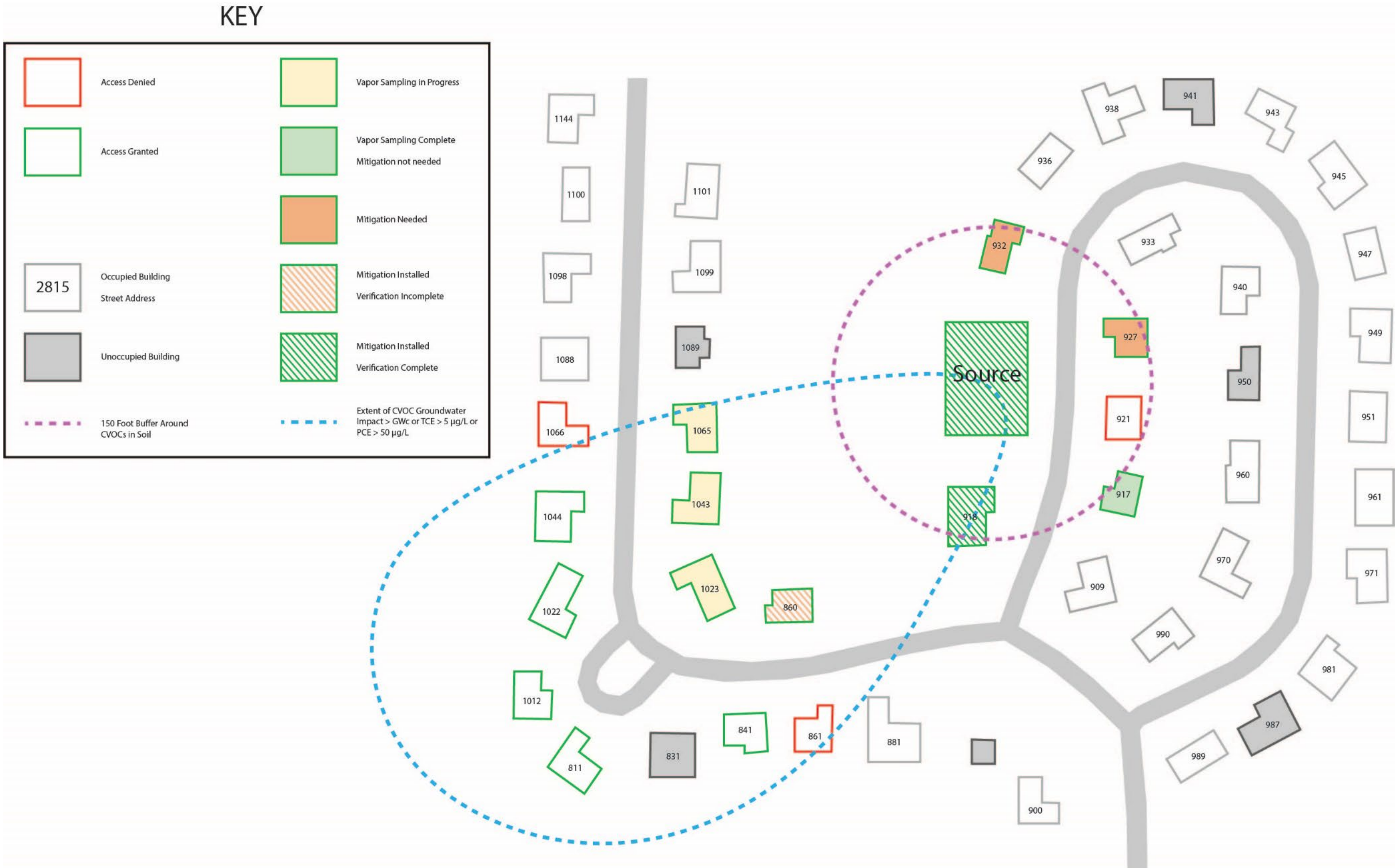
5.2.2 Addressing Variability

Vapor concentrations may be highly variable over time and in space. Risk decisions are typically based on samples collected from a small portion of the pathway, and over relatively short durations compared to the length of time occupants are breathing air in the structures being assessed. Collecting an adequate number of samples spatially may be impractical.

Even if the source concentrations remain stable or decrease, many factors may increase indoor air concentrations or risk after the investigation is complete, including building occupancy, building management and modification, integrity of the building foundation, water table elevation, nature of the land surface, and meteorological conditions. Many of these factors cannot be easily monitored or controlled after case closure with a CO (e.g., the effect of new pavement around a building). Variability over time should be considered during development of the CSM, conducting the field investigation, and choosing appropriate mitigation and remedial actions.

The variable nature of the vapor pathway is a factor in case closure decisions; the DNR cannot close a case if the remaining level of contamination is likely to cause a VAL to be attained or exceeded in the future (Wis. Admin. Code § NR 726.05(4)(e)). See Section 10.4 and Section A4.10 for additional discussion of future vapor risks.

Figure 5. Recommended VI field investigation status map



6 Vapor Intrusion Risk in Occupied Buildings

Modelling studies and results from previous investigations indicate the distances that contaminated vapors may migrate in various settings. When screening, compare the known location and concentration of volatile contaminant sources with the location of occupied buildings to assess whether the buildings are within screening distances and possibly at risk for VI (see Sections 2.4, 2.5 and 5.1). This is commonly referred to as an “inclusion zone.” After collecting initial environmental samples that confirm a hazardous substance discharge to the environment or environmental pollution, the DNR recommends screening for VI risk to assess whether any buildings should be sampled quickly, even in advance of submitting a formal site investigation workplan to the DNR. For example, if results from a Phase II Environmental Site Assessment are high concentrations of TCE in soil beneath an occupied building. The DNR recommends contacting the DNR project manager and sampling at risk buildings quickly to evaluate indoor air for acute risk in advance of submitting a site investigation work plan.

It is recommended that the RP conducts the VI screening step any time additional data is obtained during the site investigation and re-evaluates when there is new data or a change in conditions. The RP must provide data and screening evaluation to the DNR to justify why sampling is not recommended at an occupied building within the recommended screening distances (Wis. Admin. Code §§ NR 716.09(2)(f) and NR 716.15(3)(h).

6.1 Petroleum Compounds

PVOC vapor migration differs from CVOCs. Vapors from petroleum hydrocarbons rapidly biodegrade in unsaturated vadose zone soils with sufficient oxygen content. This biodegradation frequently allows VI to be ruled out during the screening phase for PVOCs. Figure 3 provides screening recommendations for petroleum compounds.

6.2 Chlorinated Compounds

Unlike PVOCs, CVOCs do not readily degrade in vadose zone soils. Groundwater can carry dissolved phase CVOCs long distances. When CVOC contamination is in the water table, the CVOCs can volatilize off the groundwater into the vadose zone. Utility conduits can take CVOCs long distances from the source and in directions different from groundwater movement. PCE and TCE are the CVOCs that most commonly present a vapor risk at contaminated sites in Wisconsin. Vapors from these chemicals pose health risks at low concentrations that are not detectable by odor.

Consequently, properties downgradient and along other preferential pathways from the CVOC sources require a field investigation that includes vapor. The DNR recommends investigation of the VI pathway for buildings that meet one or more of the screening distances listed in Figure 2 (Wis. Admin. Code §§ NR 716.11(3)(a), (5)(a) and (5)(g)).

VI Screening for Other Compounds
This guidance does not provide specific recommended screening guidelines for compounds other than PVOCs and CVOCs. See the VISL Calculator and *Guidance: Wisconsin Vapor Quick Look-Up Table, Indoor Air Vapor Action Levels and Vapor Risk Screening Levels* (RR-0136) for instructions on applying Wisconsin’s input values in the VISL Calculator.

See DNR guidance documents *Development at Historic Fill Sites and Licensed Landfills: What You Need To Know* (RR-683), *Development at Historic Fill Sites and licensed Landfills: Guidance for Investigation* (RR-684), and *Development at Historic Fill Sites and licensed Landfills: Considerations and Potential* Problems (RR-685) for screening, investigation, and mitigation recommendations related to methane (go to dnr.wi.gov and search the publication number).

If VI from compounds other than PVOCs or CVOCs is suspected at a contaminated site, the DNR recommends discussing specific screening and investigation methods with the DNR project manager.

7 Vapor Mitigation Without a VRSL Exceedance

When screening indicates the possibility of VI, sub-slab vapor sampling is required to investigate the VI pathway at occupied buildings (Wis. Admin. Code § NR 716.11(5)(g)) and to satisfy the criteria for case closure (Wis. Admin. Code § NR 726.05(8)). To comply with these requirements, samples sufficient to characterize the vapor concentrations in and around buildings that are at risk are needed; however, some scenarios justify a different approach, as described below.

In each of the following scenarios, the mitigation construction documentation, performance verification testing and long-term OM&M plan must be submitted to the DNR to demonstrate protection from VI (Wis. Admin. Code §§ NR 708.11(4), NR 708.15, NR 724.13, NR 724.15, NR 724.17, see Appendix F). In addition, COs (see Sections 12 and 13) will be assigned at properties with these systems (Wis. Stat. § 292.12(2)).

When CVOCs are present, the DNR is likely to require submittal of annual inspection logs (Wis. Admin. Code §§ 724.13(2)-(3) and NR 727.05(1)(b)(3)). DNR recommends annual inspection of VMS by September 30 and submittal of inspection logs by October 15 when CVOCs are present.

The DNR recommends contacting the DNR project manager when considering this strategy.

7.1 Preemptive Vapor Mitigation

RPs may not select preemptive mitigation in lieu of sampling for existing buildings where screening indicates a potential VI risk (Wis. Admin. Code § NR 716.11(5)(g)), with one exception – when the RP has exhausted efforts to get permission to conduct sampling from the property owner, and the property owner will only allow mitigation. If this occurs, the DNR recommends the following:

Preemptive Vapor Mitigation is when a VMS is installed when vapor screening criteria are exceeded, but sub-slab vapor samples have not been collected to determine if subsurface conditions create a potential vapor intrusion risk.

- Document best efforts to perform sub-slab vapor sampling at the off-site property (see Section 4.4).
- Allow the DNR and DHS (and potentially the local health department) an opportunity to inform the off-site property owner of the potential health risks and need for sampling.
- Provide the DNR with written documentation that:
  - Verifies that the off-site property owner grants permission for mitigation but not investigation; and
  - Clarifies that the off-site property owner understands the property will be included on the Remediation and Redevelopment Program Sites Map (RRSM) with vapor related COs, including for OM&M of the VMS.
- Communicate with the property owner to ensure they understand the VMS will be inspected on an annual basis by the RP unless another person is designated.

7.2 VMS Installed During Sampling

A VMS may be installed concurrent to collection of sub-slab vapor and indoor air samples when there is a high likelihood that indoor air concentrations could be above VALs in occupied buildings. The VMS may be installed prior to receiving the sampling results. For example, known groundwater or soil concentrations, or sub-slab vapor and indoor air results from adjacent structures may indicate a likelihood of an existing or future VAL exceedance; collection of sub-slab vapor and indoor air samples and laboratory turnaround times may delay mitigation of exposure to humans.

7.3 VMS Installed Based on Lines of Evidence

Complete characterization is not always practicable. A VMS may be installed when multiple LOEs indicate a likelihood of VI, but when the risk of VI has not been confirmed through a VRSL or VAL exceedance. LOEs may include soil contamination beneath the building, poor foundation conditions, preferential pathways, soil and groundwater laboratory results, and potential changing future conditions (see Section A3).

8 Investigating the Vapor Pathway

8.1 Work Plan

The DNR recommends screening for vapor intrusion as soon as possible following discovery. The RP must prepare and submit a work plan to the DNR within 60 days of receiving notification that a site investigation is required (this notification is commonly included in the RP letter) (Wis. Admin. Code § NR 716.09). The work plan must include the sampling methods, parameters, quality control measures, and scope of the investigation (Wis. Admin. Code § NR 716.09(2)(f)). The DNR recommends including a summary of the VI screening in the work plan as the basis for the scope of the proposed VI field investigation.

If TCE is present, the 60-day timeframe to submit a workplan may not be protective to human health. In such situations, the DNR recommends contacting the DNR project manager as soon as possible and following an expedited schedule.

8.2 Analyte List, Laboratory Methods and Laboratory Selection

8.2.1 Analyte List

The DNR recommends limiting the list of analytes reported by the laboratory to the COCs and breakdown products. For example, an investigation of a discharge of PCE should include PCE, TCE, *cis*- and *trans*-1,2-dichloroethylene (1,2-DCE)[14]. If the COCs are uncertain, the laboratory may report the full list of VOCs for the first round of samples.

When conducting indoor air sampling to quickly assess acute risk, it may be appropriate to reduce the analyte list further (e.g., only testing for PCE and TCE).

Limiting the analyte list helps to focus the evaluation and may reduce time and expense evaluating and explaining VAL or VRSL exceedances from background sources unrelated to the discharge (e.g., benzene and naphthalene due to smoking, acetone from cleaning solutions). See Section 9.1 regarding background sources.

Contact the laboratory in advance of each vapor sampling effort to discuss sampling equipment, analytical methods, data quality objectives, limits of detection, suspected VOC concentrations and any precautions requested by the laboratory to protect its equipment.

An expanded analyte list may be needed when compounds may help identify the source of contamination. For example, the presence of chloroform and bromodichloromethane can point to a municipal sewer as the source of contamination.

8.2.2 Laboratory Methods

The laboratory methods selected will depend on the sampling devices, methods and data quality objectives. U.S. EPA Method TO-15 is a common laboratory method to analyze vapor samples collected in evacuated canisters (whole-air) for VOC. Another example is U.S. EPA Method TO-17 for analysis of active sorbent samplers. Other laboratory methods are available for different sampling devices and methods. Discuss method alternatives with the laboratory to select one appropriate for the site.

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[14] Prior to this revision of the guidance, DNR had typically recommended that the list of analytes for a discharge of PCE or TCE include vinyl chloride. However, DNR review of thousands of vapor sample results has found little evidence of VI from vinyl chloride related to a discharge of PCE or TCE. DNR recommends analyzing for vinyl chloride only if site specific conditions warrant, such as a discharge of vinyl chloride, extremely high concentrations found in other media, or differentiating vapor pathways (for example determining whether indoor air is being impacted via a conduit or sub-slab intrusion).

8.2.3 *Quality Assurance/Quality Control*

Quality assurance/quality control (QA/QC) samples submitted to or tested by the laboratory may include temperature blanks, trip blanks, equipment blanks, field blanks, field duplicates, method blanks, matrix spikes and matrix spike duplicates. QA/QC samples are used to evaluate whether contamination was introduced during transportation, sample collection and analysis; QA/QC samples are also used to assess the validity of the laboratory analysis.

Air sample results can vary even when following accepted sampling and analysis methods. For example, the acceptance criterion for U.S. EPA Method TO-15, is less than or equal to 25% relative percent difference (RPD) for two analyses of the same control sample within the same laboratory[15]. Evaluation of duplicate TO-15 analysis found 20% of the samples varied by more than 300%.[16]

The DNR recommends collection of QA/QC samples when sampling error is likely to be greater and fewer samples are used to make risk decisions or decisions are time critical, such as quantifying TCE concentrations in indoor air when women who are or may become pregnant are present. For some types of sampling, such as passive thermal sorbent, the laboratory may recommend use of trip blanks. Other quality control measures are discussed in the respective sections for the specific methods of this document.

8.2.4 *Laboratory Selection*

The DNR does not regulate laboratory certifications for air sample analysis and recommends using laboratories accredited by The National Environmental Laboratory Accreditation Conference Institute[17]. Contact the laboratory in advance of each sampling effort to discuss reserving sampling equipment, analytical methods, QA/QC needs, data quality objectives and limits of detection, suspected VOC concentrations and any precautions requested by the lab to protect sampling equipment.

8.3 Investigation Methods, Number of Sample Locations and Events

The DNR recommends using the initial CSM (see Section 5 and Appendix A) to guide collection of soil, groundwater, surface water, preferential pathway, and soil gas samples to delineate the nature, degree and extent of contamination for the vapor pathway. The following sections include recommendations for sampling in media and locations that are typically part of a VI field investigation. See Section 2.5 for additional recommendations specific to PVOCs.

8.3.1 *Soil*

Collect enough soil samples to characterize the source (Wis. Admin. Code § NR 716.11(5)(e)). Include COCs on the analyte list that may pose a VI risk. Sampling may be difficult around buildings and utilities (see Section A3.3).

Other Site Investigation Activities
Samples in addition to those collected for the purpose of evaluating the vapor pathway may be needed to attain a complete site investigation (e.g., defining the nature, degree and extent of contamination in all affected media). Site investigation data along with the vapor screening assessment (see Sections 2.4, 2.5 and 6) are used to determine whether sub-slab vapor and indoor air sampling is required (Wis. Admin. Code § NR 716.11(3)(a)) and are used to update the CSM.

[15] McAlary 2015. U.S. EPA 2019.
[16] McHugh 2018.
[17] Visit https://nelac-institute.org/.

8.3.2 *Groundwater*

For factors to consider when designing a groundwater sampling plan for vapor forming constituents, see Section A3.3.

8.3.3 *Preferential Pathways*

See *Guidance for Documenting the Investigation of Human-made Preferential Pathways including Utility Corridors* (RR-649) for sampling recommendations related to human-made preferential pathways. Additional recommendations for investigating preferential pathways are below.

Building Conduit Sampling Locations and Events

The selection of conduit sampling locations is building-specific and depends on whether the building is in the contaminant source area, or away from the source area on an off-site property.

- For buildings away from a soil or groundwater source, a VI concern is movement of vapor from a sewer main into the building through the lateral. If possible, sample in a plumbing cleanout closest to the sanitary sewer lateral; the closest access point is the next best location.
- For a source area building, all wastewater from the building's plumbing system typically passes the plumbing cleanout closest to the sanitary sewer lateral. Sampling at this location can show the likelihood of impact beyond the building envelope or off-site. Beyond that, sample from floor drains, cleanouts, or behind other p-traps in areas where disposal is suspected. Plumbing conduits allow more free movement of vapors compared to sub-slab soils. Sampling every possible conduit location isn't expected in large buildings.
- The DNR recommends sampling water within sumps and air within temporarily sealed sump headspace in most cases. Samples from sumps may reveal different and possibly unknown sources, such as groundwater or foundation water, are often unsealed within the building, and may discharge to the land surface as opposed to into the plumbing system. Other plumbing vapor samples may not account for vapors in the sump.

Use of Evacuated Canisters in Plumbing Systems

In *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649), the DNR recommends using evacuated canisters to collect grab samples from within building plumbing conduits and usually performing two or more sampling events. Although the concentration measured using this technique may be accurate for the specific location and duration sampled, laboratory results can vary by one to four OM when sampling is repeated during different time periods. Differences in results may be a due to air exchange through plumbing systems. Plumbing systems are connected to the atmosphere by stack vents above the roof. Wind, and changes in barometric pressure can cause flow into and out of the plumbing system. Discharge of wastewater can cause outdoor air to enter the plumbing system. In colder periods, the temperature differential between conduit gas and outdoor air can draw sewer gas upwards, similar to the stack effect in the occupied space.

Consider the following recommendations for timing and duration of sample collection:

- ***Winter assessment period event:*** Conduct at least one sampling event during the winter assessment period to assess the impact of colder conditions.
- ***Follow-up sampling events:*** Multiple sampling events may be needed to determine the risk to indoor air quality. COCs above the VAL during the initial sampling within conduits that are either within or immediately outside the building indicate a potential risk to indoor air quality. Additional sampling locations may be needed during a subsequent round to pinpoint the source or extent of

contamination.

- ***Plumbing use – short duration events:*** Avoid using the plumbing system one hour before and during sample collection to the extent possible to limit outdoor air intrusion into the plumbing system.
- ***Passive sorbent sampling:*** Use of longer duration passive sampling may reduce the number of sampling events needed. Sampling over one to two week durations is likely to provide concentrations that are more representative of conditions compared to short duration grab samples. Leaving passive samplers in place for an extended period may not be an option for some locations, such as plumbing features that are being used. However, unused sinks and floor drains may provide an accessible point to sample. Water in any p-trap should be removed prior to placement of the sampler, and the sampler and conduit opening sealed to prevent intrusion of sewer gases into indoor air, or intrusion of indoor air into the sampler. Some cleanouts may provide an opportunity to seal the sampler in an extension to the cleanout opening such that the sampler is open to conduit vapor but not impacted by wastewater.
- ***Air conduits:*** Passive sorbent sampling may be an option for detecting the presence of contaminant in VMS or HVAC conduits and can complement grab canister samples. However, higher air flow rates may bias the result and cause it to be high. Consult with the laboratory on selection of a sampler, sampler placement, and interpretation of results.
- ***Active sorbent tube sampling:*** Active sorbent tube sampling is an alternative to canister sampling. However, the large range of contaminant concentrations, particularly in source buildings may pose a challenge for laboratory analysis. The DNR recommends using the following method for collecting a sample with a pumped sorbent tube:
    - Consult with the laboratory to determine necessary pre-screening (such as with a PID), sorbent material, pumping rate and pumped volume to achieve the VAL for the building but avoid breakthrough (the sorbent becomes saturated and provides a biased low result as some contaminant is lost).
    - Access air in conduits, below p-traps if necessary, as recommended in RR-649.
    - If tubing is snaked through water in a p-trap, push at least one tube volume of air through the tube to clear out any water in the tubing.
- ***Evacuated glass bottles:*** Evacuated glass bottles with volumes of 1 liter or less are commonly available and may be an acceptable alternative to canisters for collecting air samples for TO-15 analysis from conduits, sub-slab vapor, soil gas or other media where the smaller volume is sufficient to achieve recommended reporting limits.

- ***Documentation:*** Sampling of conduits often necessitates unique configurations. Provide photographs, sketches and descriptions that portray the procedures used.

Building Preferential Pathways other than Conduits/Plumbing Systems

As part of the site investigation, RPs must evaluate preferential pathways. (Wis. Admin. Code § NR 716.11(5)(a). This may include hollow foundation walls (as found in cinder block construction), large gaps where foundation elements meet, elevator shafts, heating, ventilating, and cooling ducts beneath the slab, chimneys, false ceilings and other similar pathways. Any of these features can act as a conduit and provide relatively direct movement of contaminated vapors into the building in response to interior pressure changes. In most cases, movement of contaminated vapors will occur into the source building where contaminated soil directly underlies the foundation or into buildings at off-source properties where contaminated groundwater occurs close to the foundation.

Sampling of such features is not always necessary; the decision to sample specific pathways is based on the likelihood that the pathways intersect a highly contaminated area.

Contaminant type is also a factor when deciding whether to sample other preferential pathways. Shorter-term spikes are of concern when a contaminant with acute risks like TCE is present, versus a chronic contaminant like naphthalene.

Consider the size and complexity of the building, and the likelihood that indoor air sampling will reveal VI through one of these pathways. For a small residential structure, one short-duration sample in the basement may be sufficient. However, in larger, complex buildings, a few indoor air samples may fail to reveal VI through preferential pathways.

When an elevator is present, it is recommended to use longer duration samplers; elevator pits often extend well below the foundation, sealing is often unknown, and operation can create repeated negative pressure cycles.

Real-Time Samplers and Screening Devices – Reporting Limits
If a real-time sampling or a screening device is used to evaluate a risk to indoor air or supplement an investigation, the DNR recommends a reporting limit for the device below the VAL. Photoionization detectors (PID) can provide a quick indication of the locations of higher contaminant concentrations and potential indoor air sources; however, most are not chemical-specific and do not meet reporting limit criteria. When using a real-time sampling or screening device, document that the device was calibrated on the day of sampling and include the documentation with the screening results. In addition, the DNR recommends following up with collection of samples that will be analyzed at a laboratory.

Active Sorbent Tube Sampling of Building Conduits
Although collection of grab samples from building conduits using an evacuated canister is the primary method recommended in RR-649, given the high concentration variability in such settings, collecting larger volumes of air over longer durations will improve characterization of concentrations with building conduits. Additional advantages of pumped sorbent tubes are a longer shelf life, reduced shipping cost, and less risk of subjecting a canister to compounds such as hydrogen sulfide. However, the large range of contaminant concentrations particularly in source buildings may pose a challenge for laboratory analysis. DNR recommends using the following method for collecting a pumped sorbent tube:

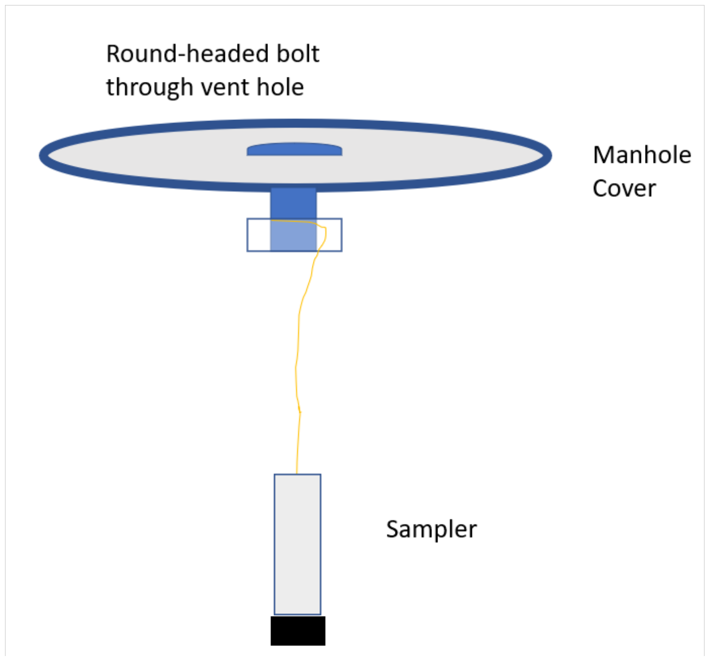
- Consult with the laboratory to determine the proper sorbent(s), pumping rate, pumped volume, and inform them of expected contaminant concentrations if known.
- Access air in conduits, below p-traps, if necessary, as recommended in RR-649.
- Pre-screen conduit air with a PID and provide this information to the laboratory with the sample.
- For plumbing conduits, ensure that plumbing above and below the sampled location is not used during the duration of sampling.
- If tubing is snaked through water in a trap, blow at least one tube volume through the tube to ensure removal of any water in the tubing.
- Collect a sample over a duration of approximately 30 minutes if possible, pumping at a rate recommended by the laboratory that will attempt to achieve the VAL for the building but avoid breakthrough.

Passive Sorbent Conduit and Manhole Sampling
Because contaminant concentrations can vary significantly over even short durations in utility conduits, using passive sorbent samplers over longer durations in settings such as sanitary sewer manholes, indoor plumbing conduits and VMS vents is becoming more common than evacuated canisters (at the date of publication). Passive samplers are available that are suitable for humid conditions, which may pose a challenge for canisters. Leaving passive samplers in place for an extended period may not be an option for some locations, such as plumbing features that are in use. Pumped sorbent tubes may also be a suitable alternative to canisters. An option for sampling in VMS vents is to insert the sampler

(wrapped with appropriate tape) into a hole drilled into the PVC pipe.

The DNR recommends using passive samplers for long duration sampling over evacuated canister grab samples when evaluating vapors in sanitary sewer mains via manholes based on significant variability over time in investigations in Wisconsin. Section 8.5.3 provides appropriate reporting limits and additional recommendations for the use of passive samplers to assess contaminant concentrations within conduits. Use of passive samplers over longer durations may also be a consideration for how many sampling rounds are needed to characterize vapor concentrations in the conduit. The DNR recommends the approach outlined below to place passive sorbent samplers in manholes, although other approaches may also be acceptable:

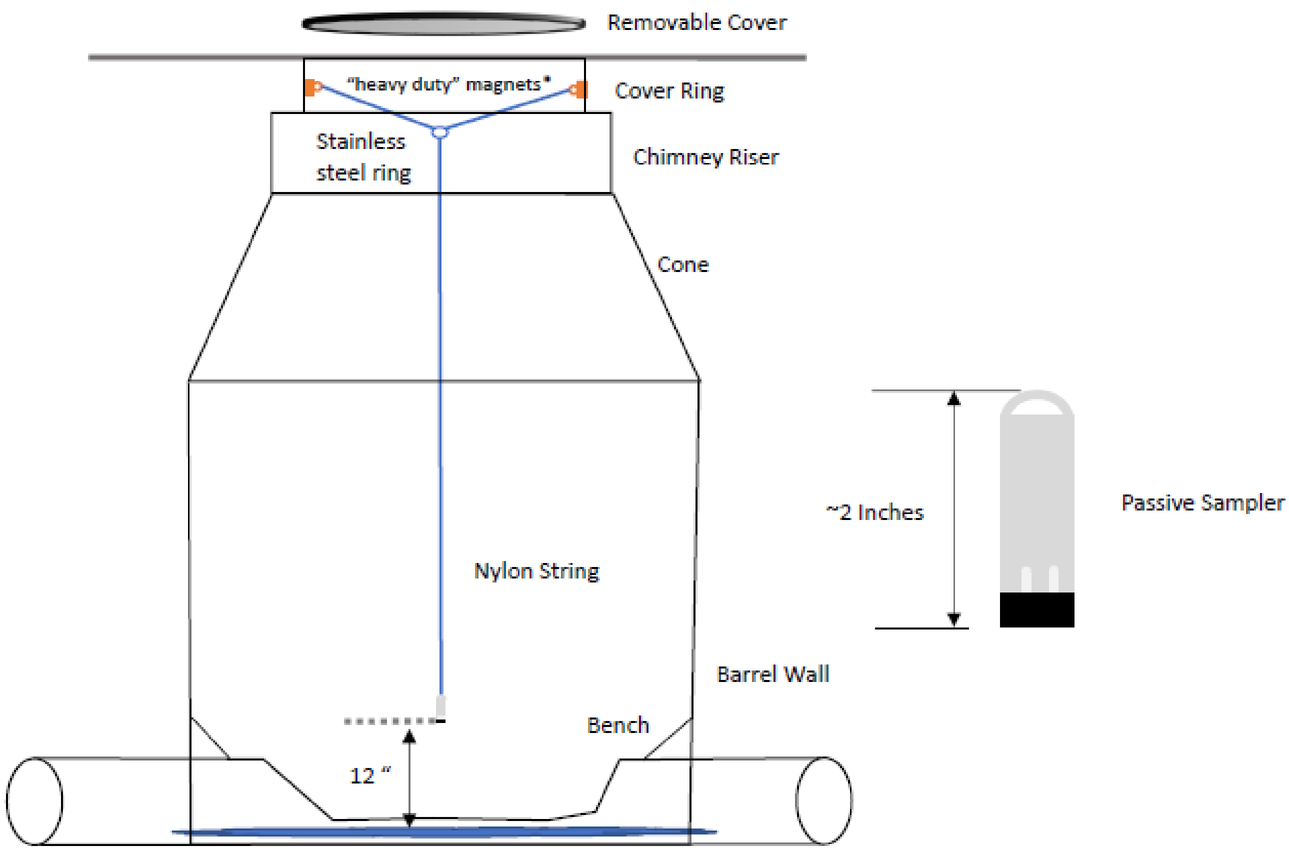
Figure 6. Sanitary Sewer Manhole Passive Sampling



- ***Liquid depth*:** Measure the depth from the top of the manhole cover to the liquid elevation at the bottom of the manhole.
- ***Vented Manholes*:** Hang the sampler from a round headed bolt and washer placed through the vent hole.
- ***Unvented Manholes*:** Suspend the sampler from magnets attached to either the underside of the manhole cover by a single magnet or the collar using two or more magnets (see Figure 6). Any rust at the attachment points should be removed to ensure a secure placement. The sampler should hang near the center of the manhole.
- ***Sampler Depth*:** Hang one sampler as close to one foot above the liquid elevation as possible while minimizing the risk of the sampler being submerged[18]. A second sampler could be placed at mid-depth as a backup in the event the lower sampler became submerged.

[18] Use information from the sewer owner, observed flow, and expected weather conditions to make the determination for this distance.

Figure 7. Sewer Diagram



*Neodymium magnets of at least 30 lb capacity, use 2-3 per sample

Follow-up Sewer Manhole Sampling

The DNR recommends follow-up sampling if results from initial sampling indicate more investigation is warranted to fully rule out VI through utility conduits. In addition, based on the concern that higher concentrations of contaminants may be drawn into the sewer system during periods of greatest temperature differential between sewer air and outdoor air, the DNR recommends that at least one of the follow-up sampling events occurs during the winter assessment period. See *Guidance for Documenting the Investigation of Human-made Preferential Pathways including Utility Corridors* (RR-649) for additional information.

Liquid Sampling Within Utility Conduits

The primary media that should be sampled and analyzed from sewer pipes is vapor; however, sampling of liquid may help identify if the source of vapor is due to contaminated groundwater entering the pipe (versus waste disposal into the pipe). The DNR has not observed a strong correlation between liquid and vapor concentrations in results received. Sampling vapor directly likely yields more representative information for assessing vapor migration of volatile contaminants within a utility conduit. The DNR recommends collecting liquid samples with disposable bailers. See *Guidance for Documenting the Investigation of Human-made Preferential Pathways including Utility Corridors* (RR-649) for additional information.

8.3.4 *Soil Gas Sampling*

Soil gas samples are collected within the unsaturated zone at locations outside the footprint of a building. Soil gas samples for CVOCs can be a *semi-quantitative screening tool* to track vapor migration pathways, identify potential source areas, and identify buildings for future sub-slab vapor testing. Results can be used to *rule in* a building or parcel as having the potential for VI. However, collecting sufficient data to *rule out* impacts to occupied buildings or vacant parcels is difficult and rarely acceptable as a stand-alone tool due to the numerous factors that can affect soil gas concentrations, even when the best available sampling methodology is used. Even permanent stainless steel gas probes placed just above the water table utilizing rigorous quality control measures have yielded results that varied more than an order of magnitude over short timeframes[19].

Soil gas concentrations are generally better than soil data at indicating previously unidentified soil contamination; soil gas samples reflect conditions over a larger area and can guide soil sampling. Soil gas sampling is helpful when trying to identify point source areas from sewer breaches or within large industrial buildings. Soil gas sampling can supplement the soil investigation similar to utilizing temporary wells for identifying suitable locations for permanent monitoring wells. A soil gas investigation can also assist in rapidly screening for the extent of the groundwater plume to *screen in* buildings for a vapor intrusion assessment and indicating when to perform follow-up groundwater sampling via monitoring wells. Section A3.4 discusses factors affecting soil gas concentrations and rationale for choosing sampling locations. In the site investigation workplan, the DNR recommends identifying how exterior soil gas samples will be used to evaluate the vapor pathway and how soil gas sampling will be conducted that meets data quality objectives for that purpose.

Active Soil Gas Sampling

Active soil gas sampling approaches vary[20]. During active soil gas sampling, a sample probe is installed into the ground, the annular space is sealed, air is purged from the sample assembly, and a soil gas sample is drawn, typically using an evacuated canister.

Practices that may provide higher quality data include:

- using permanent soil gas probes with filter media and high integrity annular seals
- using evacuated canister or glass bottle sampling instead of a sampling bag
- allowing sufficient equilibrium time after probe installation
- sampling at sufficient depth below the surface so the sample is not affected by atmospheric air; typically, at least 5 feet beneath ground surface where the ground cover is permeable
- not sampling within the capillary fringe
- not sampling at too high of a rate; typically, less than 200 milliliters per minute
- using small diameter inert tubing
- limiting above ground tubing length
- performing adequate purging of lines
- measurement of oxygen content to assess for atmospheric air intrusion
- collecting field blanks and duplicate samples

Using other methods that produce more qualitative data, such as a bar-hole probe to quickly screen for a methane risk, may be appropriate to achieve certain goals depending how the data will be used.

The DNR recommends considering the following information and recommendations when planning

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[19] U.S. EPA 2021.

[20] U.S. EPA's Contaminated Site Clean-Up Information (CLU-IN) website provides additional information on active soil gas sampling approaches. Visit https://clu-in.org/.

soil gas sampling for VI evaluation.

- ***Leak Testing:*** Perform leak testing to check for intrusion of atmospheric air through tubing, fittings, and the annular space using helium testing or another type of tracer during each sampling event for each sampling location.
- ***Canister Size:*** Avoid using 6-liter canisters near the surface or in fine-grained soils where gas movement along the annular space may be induced.
- ***Soil Conditions***: Document soil conditions in the sampling zone including lithology and moisture content.
- ***Meteorological Conditions:*** Record temperature, barometric pressure, wind speed and direction on the day of sampling and document any precipitation events within one week before sampling.
- ***Number of Sample Locations and Events:*** To account for spatial and temporal variability, the number of sample locations and events will depend on the site and purpose of the sampling. A single sample event may confirm vapor presence but establishing that vapors above a certain concentration are not a concern will likely require many rounds at many locations. There are many different recommendations on best locations to sample for assessing risk to a building.[21]

Passive Soil Gas Sampling

Passive soil gas sampling may be used to survey and locate vapor migration pathways and sources. In passive soil gas sampling, a sorbent sampling device is implanted directly into the ground that collects a vapor sample by diffusion or passive permeation in response to concentration gradients. The laboratory reports the resulting mass of contaminant adsorbed to the sorbent media.

The main advantages of passive samplers are the ability to collect a time-integrated sample over a period of days to weeks, and considerably simpler sampling methodology. This is in comparison to a sample collected over a period of less than thirty minutes with active sampling. For a variable media such as soil gas, an RP can more confidently rely on passive sampler results to reveal the presence of contaminated vapors.

Historically, passive sampling devices have been used mostly qualitatively or semi-quantitatively to indicate where concentrations are higher relative to other locations at a site. Samplers that can provide quantitative data have been developed for many contaminants and settings.

The DNR recommends selecting a sampler with an uptake rate (UR) that does not cause starvation and underestimation of concentrations in soil gas, typically about 1 mL/min or less.[22] If passive samplers are used quantitatively, the DNR recommends working with the laboratory to provide information to the DNR that supports the use of that sampler. Information necessary for DNR consideration includes confirmation of the appropriate sorbent and UR for the moisture and soil conditions at the site, sufficiently low reporting limits, and appropriate QA/QC. See Section 8.5.3 for an additional discussion of passive sorbent samplers.

If passive samplers are placed at shallow depth (typically at one to three feet) to screen for the presence of contaminants, consideration should be given to the impact of seasonal and meteorological conditions for placement and interpretation of results. At this depth, soils are more likely to be impacted by rainfall and seasonal temperature. Warmer and drier soil conditions enhance vapor movement. Frozen soil conditions and colder soil temperatures can occur at shallow soil depths during winter months; ice lenses may form that prevent contaminant vapors from reaching the sampler

[21] Recommended literature: U.S. EPA, "Conceptual Model Scenarios for the Vapor Intrusion Pathway." and Wang, "Investigating Two-Dimensional Soil Gas Transport of Trichloroethylene in Vapor Intrusion Scenarios involving Surface Pavements using a Pilot-Scale Tank."
[22] DOD 2017.

as frost penetrates the ground (frost depth in Wisconsin may reach 60 or more inches). Colder temperatures can also reduce diffusion rates. Therefore, measured concentrations could be lower in colder winter months, particularly beneath open ground. If passive soil samplers are used for screening, the DNR recommends delaying screening until warmer and drier soil conditions occur. Another investigation method may be selected or samplers may be placed below the frost depth (record and report soil temperature and frost depth to the laboratory). Passive sample results collected at a shallow depths may be used as an initial screening tool to identify whether contaminants are present and where concentrations may be relatively higher. Concentrations measured in shallow soil gas should not be solely used to screen out buildings from additional vapor sampling without other LOE.

8.4 Properties Without Buildings Prior To Case Closure

The DNR recommends that the VI risk for properties without buildings should primarily be determined by the building's proximity to vapor sources (see Sections 2.4, 2.5 and 6 for screening guidelines). Soil gas concentrations are not likely to represent the contaminant vapor concentrations below the foundation of a future building. For properties that fall within the screening guidelines for a vapor intrusion assessment, the DNR may require a VI CO for "future risk" as a condition of closure, regardless of whether soil gas samples were collected (Wis. Admin. Code §§ NR 726.15(L) and (m)). The CO may require the property owner to contact the DNR prior to any construction and may require vapor control technologies for new construction, unless the vapor pathway is assessed post-construction and the DNR agrees that vapor control technologies are not needed. (Wis. Admin. Code § NR 726.15(L)). The process to work with the DNR after closure is referred to as a post-closure modification (Wis. Admin. Code § NR 727.07) and is explained in *Guidance on Post-Closure Modifications* (RR-982) and *Post-Closure Modifications – Changes to Property Conditions After a State-Approved Cleanup* (RR-987). See also Section 10.7.

8.5 Properties With Buildings Prior To Case Closure

8.5.1 Sampling Locations and Frequency

Sampling locations and frequency are site-specific and depend on building size, construction, operation, air handling, preferential pathways, use, contaminants of concern, demographics of occupants and meteorological conditions; see Figure 4 and below.

Future Building Alterations

The DNR recommends evaluation of the vapor pathway for the proposed future use of a property in the vapor investigation, when practicable. For example, if an industrial building is proposed for redevelopment as residential-commercial mixed-use space, sample vapors under the existing building slab to determine whether concentrations exceed residential VRSLs. Vapor concentrations beneath the building may be significantly different if changes are made to the structure or operation (e.g., changes to the HVAC or partitioning of large spaces). Regardless of sampling done prior to renovation or redevelopment of a building, sampling of sub-slab vapor concentrations after redevelopment of the building is required if done prior to case closure (Wis. Admin. Code § NR 716.11(5)(g)). After closure, changes to the building structure or use would have to comply with any vapor-related COs (Wis. Admin. Code § NR 727.05). This may involve sub-slab vapor sampling or installation of a VMS through a post closure modification request to the DNR (Wis. Admin. Code § NR 727.07).

VI Building Survey

The DNR recommends using an in-depth building survey at each building location to:

1. develop a conceptual understanding of how VI may be occurring at a specific building,
2. design sample locations,
3. identify and resolve background sources, and
4. interpret sampling results including whether it is appropriate to use default AF.

Building survey activities include visually observing the features and uses of the building and the surrounding area, reviewing building layout and drawings, interviewing occupants to understand how occupants use windows and doors to ventilate the building, consulting the building engineer or other person with knowledge of the HVAC system, and conducting real-time vapor sampling. This information can help support conclusions about whether VI is occurring or has the potential to occur at a building. The DNR recommends including building survey information with the site investigation work plan, site investigation reports and or other submittals with sampling results.

8.5.2 Sub-slab Vapor Sampling

Sub-slab vapor samples are collected from unsaturated soil directly below a building foundation using sample probes installed through the slab. Sub-slab vapor sampling is required if soil, groundwater or soil gas data indicates a risk for VI (Wis. Admin. Code § NR 716.11(5)(g)), except when access is not granted or technical barriers prevent the collection of a representative sub-slab vapor sample.

Relation to Indoor Air Sampling

See *Number and Timing of Sampling Events* in Section 8.5.3.

Location of Samples

The DNR recommends sub-slab VI field investigation of the entire building for smaller buildings. If the source of contamination is groundwater of uniform concentration, one sample location near the center of the building slab may be adequate for very small buildings (i.e., less than 1,000 ft^2), but typically two are needed. If a building is separated by a footing as is commonly done with a building foundation or variable depth as commonly seen with a partial basement, sufficient sub-slab vapor locations are required to adequately investigate the vapor pathway (Wis. Admin. Code § NR 716.11(5)(g)).

For larger buildings, the scope of the sub-slab VI field investigation may be limited to the area of known contamination. Sources with greater spatial variability may require added sub-slab vapor sample locations, such as when soil contamination is beneath a portion of the building or if multiple source areas are suspected. Also, sample selection must account for foundation elements that can interrupt the movement of sub-slab vapors, such as footings (Wis. Admin. Code § NR 716.11(5)(g)). The DNR recommends selecting sample locations away from exterior foundation walls where vapors are less likely to vent to the atmosphere, unless evaluating a specific source outside the building.

Evacuated Canister Sub-Slab Vapor Sampling

In evacuated canister sub-slab vapor sampling, sample probes are installed through the foundation, an evacuated canister is connected to each probe, and the inherent vacuum of the canister pulls sub-slab vapor from a small radius of about 0.5 to 2 feet around each sample point. The radius varies based on the porosity of sub-slab conditions. Porosity will vary greatly between a slab directly on clay verses a slab on uniform base course gravel above the soil. Evacuated canister sub-slab vapor sampling can be used in almost any building that has a reasonable foundation and an unsaturated zone below the foundation. Appendix E provides specific method recommendations.

Passive Sub-slab Vapor Sampling

Passive gas samplers are available in designs that are suitable for use in small diameter slab penetrations, like typical sub-slab vapor ports. Using these samplers in at least some locations could integrate the sample collection over a longer duration, allowing increased confidence in the data. For quantitative sub-slab vapor sampling, the DNR recommends selecting samplers with a UR of about 1 mL/min or less. The DNR recommends using procedures which achieve the following:

- Isolating sub-slab passive samplers from indoor air; however, the extensive leak detection schemes necessary for evacuated canister sampling are not necessary for passive samplers because a vacuum is not applied to the subsurface. The DNR recommends that measures are taken to minimize the amount of time that the borehole is left open after drilling, to minimize air movement between indoor air and sub-slab.
- Ensuring that the face of the sampler is exposed to the sub-grade fill or native soils immediately below the slab such that the soil gas sampled is similar to that sampled with an evacuated canister. For sub-slab passive vapor sampling, the DNR recommends that the boreholes extend just beyond the depth of the slab. Samplers may also be placed at greater depths or in boreholes that extend to a greater depth to obtain soil gas concentrations that are representative of areas deeper in the soil profile. However, the primary purpose of sub-slab vapor sampling is to determine concentrations directly beneath the slab.
- Ensuring that an air gap remains around the face of the sampler during the duration of sampling. If soil is allowed to touch the face of the sampler, it may reduce the rate of diffusion into the sampler and bias calculated concentrations.
- Ensuring that the penetration through the slab is adequately sealed between sampling events and permanently sealed after sampling is completed.
- Section 8.3.4 includes additional information on passive sorbent samplers and reporting limits.
- Only one sampler should be placed within each borehole (such as when comparing different samplers). Multiple samplers placed within the same borehole can compete for contaminants and produce low biased results.

High Purge Volume Sampling

High purge volume (HPV) sampling may be used to supplement discrete sub-slab vapor port sampling at large buildings with competent foundations. HPV sampling involves extracting several hundred liters of air from beneath the slab, compared to the few liters extracted with standard sampling. HPV sampling has the potential to assess a larger area beneath the slab and help locate areas of higher concentrations; however, the higher volumes of gas extracted can cause this method to yield unrepresentative results if the vacuum extends to foundation cracks (drawing indoor air), the perimeter of the building (drawing atmospheric air) or utility bedding (drawing indoor or atmospheric air). Concentrations measured during the non-equilibrium conditions created during the HPV test may not represent those during more typical conditions. HPV sampling may not be feasible if the water table is very shallow (less than 2 feet) below the slab floor, may be ineffective in buildings with slabs on clay-rich or wet soils, or yield unrepresentative results when sub-slab material has irregular permeability.[23] In some investigations, CVOC samples from HPV tests had up to 1,000 times lower than standard sub-slab vapor samples in the same area, most likely due to dilution. HPV sampling is thought to be less influenced by seasonal atmospheric conditions than standard sampling; however, the DNR is aware of HPV tests conducted at the same location on different dates that have yielded significantly different results.[24] This method may not provide sufficiently precise information. An example of this is where the sub-slab vapor concentrations are near a suspected preferential pathway. The DNR recommends that use of HPV sampling be viewed as supplemental to standard discrete sub-slab vapor port sampling. Also, HPV sampling is not suitable for buildings overlying a deep gas-permeable vadose zone.

[23] NAVFAC 2023.

[24] The DNR is aware of four separate occasions in which HPV tests were conducted at the same location on different dates with significantly different results. At one building, HPV results from several tests never exceeded 600 µg/m3 TCE despite overlying groundwater at ten feet having 3,000 to 4,000 µg/L – a significant disparity.

Appendix D provides specific recommendations on HPV sampling.

Special Sampling Situations

Collection of a representative sub-slab vapor sample is sometimes not practicable. The DNR will consider the results of alternative sampling approaches, along with other LOE, when considering the appropriate mitigation necessary and/or vapor COs to be imposed under Wis. Stat. § 292.12. Common LOE include soil and groundwater data and presence or lack of preferential pathways.

High Water Table

The DNR recommends collecting sub-slab vapor samples during drier seasonal periods when soil below the building is unsaturated. If the building has a sump, a sample of air from a temporarily sealed sump and sample of water from the sump may be collected. If a sump pit is not available, and groundwater is in nearly direct contact with the foundation slab, groundwater samples from near the building may be collected. Sidewall vapor samples may be collected but are unlikely to represent conditions beneath the slab. Sidewall vapor sampling may be used to determine whether mitigation is necessary, but not solely to rule mitigation out.

If water is in constant contact with the foundation, indoor air sampling in the lowest level may be the only option to assess VI risk. In such cases, ruling out the need for mitigation may require numerous longer-duration samples.

Sump Sampling

The DNR recommends collecting a vapor sample from a temporarily sealed sump regardless of the presence of water. Removal of the sump pump may be needed to collect a vapor sample. If the sump pit has an airtight cover, collect the vapor sample through an opening in the cover. Otherwise, temporarily seal the sump pit so that it is airtight with a rigid material and use sealing adhesive and cover material that is VOC-free. A passive sampler that is suitable for high humidity settings may be used if there is little chance of submersion.

Alternatively, attach an air pump to a sealed port through the sump cover and vent the exhaust outside the building. The DNR recommends removing at least three to five volumes of air from the sump pit and allowing the air inside the sump to equilibrate for 24 hours. An evacuated 1 or 6 L canister sample from the sump headspace may be collected by placing the sample tubing through an airtight entry through a temporary sump cover. A flow regulator is not needed when collecting a vapor sample from a sump; the evacuated canister valve can be partially opened to allow the canister to fill, commonly referred to as a grab sample.

A leak test may be performed on the probe seal through the sump cover, depending on the configuration of the sump pit cover. A shut-in test may be performed to ensure that any compression fittings along the sample train are airtight. If water is present in the sump, a water sample may be collected from the sump on the same date as the sump vapor sampling and analyzed for the COCs.

Impermeable Sub-slab Bedding

If materials with a low gas conductivity such as native clay underlie the material directly beneath the building slab, vapor samples may not represent sub-slab vapor conditions. In these cases, the DNR recommends addressing temporal variability by adding indoor air sample locations along with either increasing the number of events or using passive samplers. Consider other LOE when making mitigation decisions.

Dirt Floor or Poor Slab Condition

A sub-slab vapor sample may be collected if there are intact portions of concrete slab, under which contaminant vapors may accumulate to a greater extent. A greater number of indoor air samples may need to be collected than usual for a similar building with an incompetent foundation. Using the default AF is not appropriate for buildings with a dirt floor, degraded and/or cracked concrete, field stone, brick foundations, etc.

Mobile (Modular) Homes

Sampling beneath the home may not be needed if the area beneath the home is open to atmospheric air or has a permeable skirt. However, if the home sits on a permanent or relatively confined foundation, the DNR recommends sampling the space within the foundation; treat this space like any other crawl space and compare vapor samples to the indoor air VAL.

Existing Radon Mitigation System

In some cases, a building may have an existing radon mitigation system. See Section F2.3.5 for recommendations on how to proceed in such a situation.

8.5.3 Indoor Air Sampling

Buildings Where Required

Except as discussed below, indoor air sampling is required any time it is necessary to determine the impact VI currently has to an occupied building (Wis. Admin. Code § NR 716.11(5)(h)). **The DNR recommends indoor air sampling when performing a VI field investigation.** Investigations have shown concentrations of sub-slab vapors to be highly variable. A few sub-slab vapor samples may not be sufficient to determine the risk to indoor air. Preferential pathways can impact indoor air quality even in the absence of sub-slab vapors and assessing and investigating preferential pathways is difficult. For these reasons, sampling indoor air is recommended as a key part of VI field investigations.

Current Use of COC

The DNR does not recommend indoor air sampling if the COC is currently being used in commercial and industrial operations. A common example of this is PCE being used at an active dry cleaner. If the COC in use can feasibly be temporarily removed, consider discussing a site-specific indoor air sampling strategy with the DNR project manager and the DHS.

General Considerations

Figure 4, Table 2 and the sections below provide recommendations for number, location, timing, and sampling methods for indoor air. Section 5 discusses the CSM for VI. In situations with elevated health risk, the DNR recommends analysis of indoor air samples on an expedited laboratory turn-around time (TAT).

Concentrations of VOC present in the indoor air near the sampling device are measured during the period of sampling. The most-used method between 2010 and 2022 was evacuated canisters; however, evacuated canister samples are typically collected over time periods ranging from 8 to 24-hours. Data from intensively sampled buildings indicate that a few samples collected over such durations may miss periods when VI is active and indoor air concentrations are higher. This dynamic can be particularly challenging if TCE is present since TCE concentrations exceeding the VAL during even short periods of time can pose an acute health risk. To adequately characterize the risk, methods to collect samples over longer durations may be used, such as using a passive sampler, or methods to create worst-case conditions (e.g., BPC) in lieu of collecting short duration evacuated canister samples.

When TCE is in Use

DHS recommends always evaluating indoor air during vapor investigations when TCE is the COC, including when TCE is in use, to assist with health risk communications with workers. This evaluation allows for decisions to interrupt exposures to sensitive populations as soon as possible to prevent the known health risks. A DHS fact sheet, *TCE in the Workplace*, provides additional information on exposure to TCE in workplace settings and is available in English, Spanish and Hmong languages. Visit dhs.wisconsin.gov, search "P-03201."

Pre-sampling Activities

The DNR recommends the following pre-sampling activities to prepare a building for indoor air sampling.

- ***Inventory and Remove Indoor Air Sources:*** Inventory and remove items from the building that may contribute VOCs to the indoor air prior to sampling. Tables 4 and 5 list common background sources by product and chemical, respectively. Instructions for occupants in Appendix B can assist with the effort to remove items that may contribute VOCs to the indoor air. However, removing a product container may not remove residual traces of the contaminant if the product was used on surfaces in the building. The DNR recommends considering how and when the product was last used.
- ***Occupant Behavior and Building Operation:*** For shorter duration sampling events in residential buildings, closing windows and doors at least 24 hours prior to sampling and keeping them closed to the extent possible (except for normal entry and exit of the building) during sampling. This will minimize contributions from outdoor air. The DNR recommends that HVAC systems, including ventilation fans, continue to operate as normal for the season, and that the operating conditions are documented and reported as part of the sampling. Determine if there are changes in operation of the HVAC system during different parts of the day or some similar variable feature that affect the amount of fresh air that is brought in. The DNR recommends not to use fireplaces unless they are part of the routine heating system and to avoid temporary systems, such as box fans. Consider sealing any broken windows. Instructions for occupants in Appendix B can assist with meeting these conditions during sampling.

The DNR recommends basing expectations for occupant behavior and building operation on the duration of sampling. It may be unreasonable to ask occupants to refrain from certain activities, such as keeping doors closed, over longer durations. For longer duration events, periodic activities, such as using a bathroom fan, are likely to have less impact on overall results than they would during a short sample duration. The instructions for occupants in Appendix B may be tailored to each specific scenario.

Sample Duration

The DNR recommends basing the duration of sample collection on the use of the building, the level of uncertainty of an acute risk, and the nature of HVAC system operation.

If data is needed quickly: A quick TAT[25] may be used to collect and analyze data if acute exposures may occur, such as when TCE and women who are or may become pregnant are present or there are very high concentrations outside of the building envelope. Samples may be collected over at least 24 hours for residential buildings and over at least the 8 hours that reflect maximum occupancy for other buildings. Collecting samples using passive sorbent samplers over a period of a few days can minimize the effect of time-varying concentrations and increase confidence in the data, even if sample collection requires a longer time period. The availability of one type of sample device, shipping and analytical TAT may result in obtaining data more quickly than a method that has a shorter sampling duration. The DNR suggests balancing these factors to provide the highest quality data within the shortest amount of time.

Some buildings, such as childcare facilities or schools, are considered residential for the purpose of determining VAL applicability. These buildings do not have residents and may have HVAC systems that operate more like those in a commercial building, with different settings depending on occupancy. For these buildings, the DNR recommends collecting shorter duration samples over the 8

[25] DHS 2021, DHS 2022. See Appendix H.

hours that reflect maximum occupancy, but to apply the residential VALs.

Longer Duration Events: If sample results are not needed quickly, the DNR recommends using longer duration sampling events to better account for temporal variability. A longer duration sampling event typically occurs over 10 days or longer. A minimum sampling duration of 7 days may be acceptable, to deal with scheduling conflicts if the reporting limits achieved are sufficiently low (see *DNR Recommended Steps in Planning and Implementing a Passive Sampling Program*, below). Sections A3.1.1 and A3.3 outline the benefit of collecting longer duration samples. These recommendations apply for all types of building uses; however, if the HVAC or other building operation creates substantially different conditions during non-work hours, these conditions may be accounted for if longer duration sampling is performed. See *Sampling Methods,* below.

Location of Samples
The DNR offers the following recommendations for location of samples.

- ***Height:*** Place indoor air sampling devices near the breathing zone, three to five feet above the ground for adult occupants and lower for child occupants, such as in a day-care center or school. Place samplers where they will not be disturbed.
- ***Building Levels:*** Sample indoor air in the lowest level of the building. Additional levels may be added based on factors such as preferential pathways, degree of occupancy, and location of sensitive occupants.
- ***HVAC Zones:*** Single family residential buildings are typically served by a single HVAC system and have well-mixed indoor air; therefore, one sample location per level is sufficient in most cases. For larger multi-family residential, commercial, and industrial buildings, consider collecting samples in different HVAC zones and spaces where greater negative indoor air pressure zones are expected. An ideal location is near cold air returns in rooms with mechanical ventilation, particularly when near highly contaminated areas.
- ***Openings:*** Place indoor air sampling devices away from windows and doors to minimize the effect of outdoor air sources.
- ***Near Points of Vapor Entry:*** If preferential pathways are suspected, the DNR recommends placing indoor air sampling devices near features such as foundation cracks, rooms with plumbing features, drains, sumps, rooms adjacent to sewer vent stacks, and within elevator pits and in stairwells.
- ***Near A Known or Suspected Source:*** If a stronger source is suspected on sides of the building or beneath the slab in certain areas due to soil contamination, indoor air near these sources may be sampled.

Number and Timing of Sampling Events
The DNR offers the following recommendations pertaining to the number and timing of sampling events.

- ***Relation to Sub-slab Sampling:*** Until it is determined that mitigation is necessary or VI is ruled out, the DNR recommends pairing indoor air sampling with sub-slab vapor sampling within 48 hours of each other. Typically, with canister sampling, indoor air sampling may be completed just prior to sub-slab sampling to eliminate the potential release of contaminants into indoor air during collection of the sub-slab vapor. This may not be feasible when using passive samplers over longer durations. Minimizing the duration that the sub-slab boreholes are open should reduce risk of cross-contamination. Waiting a couple of air exchanges after sealing the slab, prior to placing indoor air passive samplers is also an option. Collecting sub-slab vapor samples to determine locations of indoor air samples may be acceptable due to the complexity in commercial and industrial buildings. However, if TCE and women who are or may become pregnant are present, or there are very high concentrations outside of the building envelope, the DNR recommends collecting indoor air samples immediately after the building screens in for a VI risk to quickly assess the potential for acute risk.

- ***Relation to Preferential Pathway Sampling:*** The DNR recommends collecting indoor air samples within 48 hours of preferential pathway sampling events. Typically, indoor air sampling is completed just before conduit sampling to eliminate the release of contaminants into indoor air during sample collection. If passive samplers are used in conduits, place the sampler in the conduit taking steps to minimize vapor entry into indoor air. Waiting a couple of air exchanges after sealing the conduit, prior to placing indoor air passive samplers is also an option.
- ***Initial Sampling:*** The DNR recommends collecting samples as soon as possible after screening reveals a risk to quickly determine if acute exposure is occurring. This is particularly true if TCE is a COC and either women who are or may become pregnant are present or concentrations in other media suggest acute/immediate action levels may exist[26].
- ***Follow-up Sampling:*** After initial indoor air sampling, the timing and number of follow-up events depends on the following factors:

  1. the type and concentration of contaminant;
  2. concentrations found during the initial event;
  3. time of year and meteorological conditions during initial sampling; and
  4. building occupants.

  Table 2 incorporates these factors into recommendations for follow-up sampling.

- ***Complementary Data:*** The DNR recommends collecting any data or other information that may affect VI to help evaluate whether sampling occurred during a period of RME. These data may include indoor and outdoor temperature, wind speed and direction, barometric pressure, and sub-slab to indoor air pressure differential.

Sub-slab to indoor air pressure differential is the primary control over VI. Collecting these data can aid in determining the direction and strength of vapor movement. Highly variable pressure differentials and time lags can complicate efforts to relate pressure differentials to contaminant concentrations. Pressure differential data are most useful when continuously recorded for a longer period than the sampling period. A continuous record better indicates whether the contaminant sampling took place when VI was actively occurring. The DNR does not recommend using indoor to outdoor air pressure differential as a surrogate for sub-slab to indoor air pressure differential. A recent study found indoor to outdoor pressure differentials rarely correlated well with sub-slab to indoor air pressure differentials[27].

Sampling Methods

Canister Sampling

With this approach, indoor air sampling is drawing air into an evacuated canister using a flow controller at a rate of no more than 200 mL/min. The resulting sample is a direct measure of the indoor air concentration near the sampling device during the sampling period. The DNR recommends fitting each canister with a flow controller that provides a time-weighted average concentration. Appropriate sampling durations include 24-hours for residential buildings, or 8-hours for commercial and industrial buildings. When an evacuated canister is used for indoor air sampling, **DNR recommends using a 6 liter canister any time the sample duration exceeds two hours**.

[26] For example, ≥ 3X VAL or VRSL for a NC or ≥ 10X VAL or VRSL for a C.
[27] Buckley et al. 2022.

Long Duration Canister Sampling

Several devices have been developed that allow collection of a sample over durations longer than 24 hours. Critical orifice controllers restrict flow using a length of capillary tubing or a machined orifice. Capillary controllers have allowed the collection of a sample for a period up to 14 days with a 6-liter canister, and up to 60 hours with a 1-liter canister[28]. One study found that sample results from an evacuated canister over a 14-day period were similar to the average of 14 consecutive evacuated canister samples collected over the same period[29]. Another study found an RPD within 20-50% between a field gas chromatograph and two-week capillary samples collected sub-slab[30]. However, given its limited use, the ability of this method to produce reliable data in all conditions is uncertain. Some devices may not provide a reliable flow rate and may be affected by high humidity or be prone to clogging by fine particulates. Development and improvement of flow controllers is on-going. The DNR suggests working closely with the lab to ensure that any device used provides a reliable time-weighted average concentration for the setting being sampled and provide sufficient supporting documentation to the DNR.

Passive Indoor and Outdoor Air Sampling

With passive indoor air sampling, a device with sorbent media is set up to collect a sample via diffusion or passive permeation. The mass of contaminant adsorbed is then extracted in the laboratory for analysis.

Passive samplers can be advantageous primarily because they collect data over a longer period with less intrusion upon occupants and greater convenience for environmental consultants and occupants due to the small size and simple setup. The long shelf-life of some samplers allows them to be kept on hand. When the sampler and sorbent are appropriate for the setting, passive indoor air sampling can provide quantitative results that can be compared to VAL for most compounds of interest.

Compared to canister sampling, a passive sampling investigation requires additional planning for consideration of factors that can affect results. Factors include contaminant characteristics, sampler and sorbent type, and ambient conditions of air flow, humidity, and temperature. Work with the laboratory when undertaking a passive sampling program to select samplers and analysis based on site conditions and data quality objectives.

Not all passive samplers are optimal for providing results with a quick turnaround time; however, some samplers with a higher UR can provide a sample with sufficient reporting limits with sample collection durations less than 24 hours. The *Standard Guide for Placement and Use of Diffusive Samplers for Gaseous Pollutants in Indoor Air* by ASTM International provides recommendations for placement of passive samplers in indoor settings.[31]

The laboratory will extract the COC from the sorbent material and report the result as the mass of contaminant retained by the sampler. The laboratory calculates the contaminant concentration in air based on the UR and the duration the sample was collected. In Equation 2 below, the sampling duration and mass are determined with a high degree of accuracy. Determining the UR is the key to accurate calculation of contaminant concentrations. URs have been empirically determined in a controlled chamber where the concentration is measured with another method for most common samplers and COCs assessed in VI field investigations. The UR can also be estimated from known free-air or membrane diffusion coefficients and sampler geometry. The UR can be verified in the field if the concentration in air is measured precisely with another method, such as with a gas chromatography/electron capture detector (GC/ECD) or gas chromatography/mass spectrometer

[28] DOD 2019.
[29] DOD 2020.
[30] Buckley et al. 2022.
[31] Additional literature: U.S. EPA 2024 and NAVFAC 2015.

(GC/MS) device. This verification can be useful if field conditions deviate substantially from conditions during empirical measurement of URs in a laboratory setting.

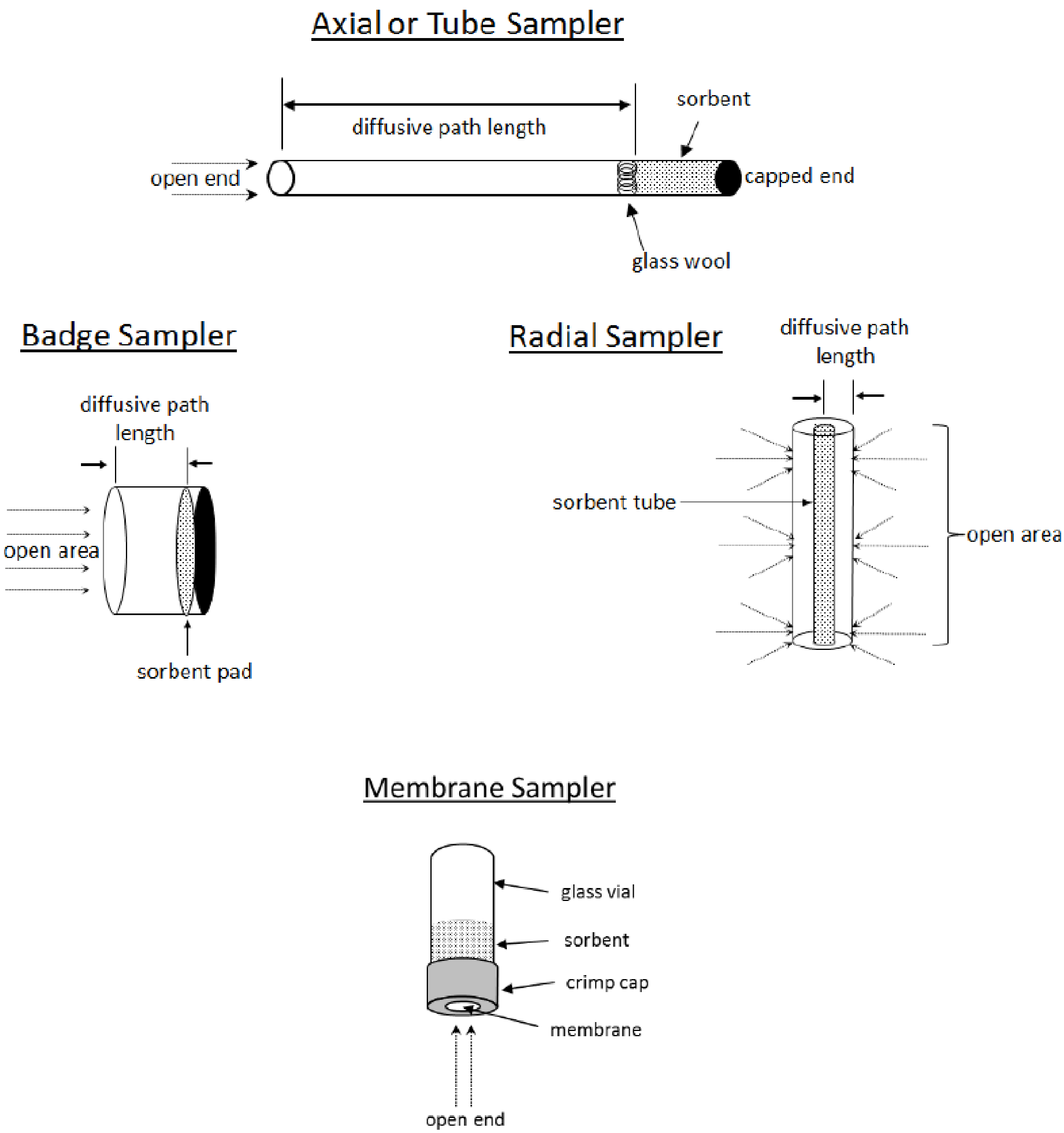
Equation 2. Time-weighted Average Air Concentration

$$C_{coc} = \frac{M}{UR \times t}$$

Where: **C_{coc}** = time-weighted average air concentration (µg/m^3)
M = mass of VOC retained by passive sampler (µg); reported by lab
UR = uptake rate (mL/min, compound-specific); aka sampling rate (device-specific)
t = sample duration time (min)

The two main categories of samplers are diffusion and passive permeation. Diffusion samplers rely on diffusion through a stagnant air region in the sampler. Passive permeation samplers have a thin hydrophobic polymer membrane between the sorbent and ambient air that has a predictable permeation rate. Most commercially available diffusion samplers are one of three geometries: axial, badge, and radial (see Figure 8). Axial samplers typically have a low UR because of their small cross-sectional area and long flow path. Badge samplers have a higher UR due to the large surface area and short flow path. Radial samplers have a high UR due to the very large surface area and short flow path.

Figure 8. Passive Sampler Types



Images courtesy NAVAC Geosyntec

Sorbents are generally of two types: those that are analyzed in the lab by thermal desorption, and those that are analyzed by solvent extraction. The laboratory will recommend the appropriate combination of sampler and sorbent based on the COC, expected concentrations, media sampled, sampling conditions, sample duration, and required reporting limits.

Recommendations for Using and Placing Passive Indoor Air Samplers

- ***Breathing Zone Sampling:*** See *Location of Samples*, above. The small size of passive samplers allows for more flexibility for placement compared to canisters. However, because sample durations are longer, interference with occupant activities must be considered for longer periods of time. Some samplers have small parts that must be kept out of reach of young children.
- ***Commercial/Industrial Buildings:*** In commercial and industrial settings, the DNR typically recommends sampling during the 8 hours that reflect maximum occupancy. This timing can present a challenge for collecting longer duration samples. If building operations of the HVAC and ventilation fans are not substantially different during non-business hours, it may be appropriate to collect samples during a continuous period of several days. However, if the building operations are substantially different during non-business hours, continuously deployed passive sampler results may not reflect concentrations during maximum occupancy. For such situations, a passive sampler can be used to collect a sample over multiple days but only left open during work hours and isolating the sampler by placing it in a sealed container during non-work hours. Some devices include a cover for the sampler opening. Another option is to place some samplers over a longer duration, but collect a few shorter duration samples (canister, TO-17, higher UR passive sampler) during 8 hours on the first or last day of the longer duration sampling event. Record all periods during which the sorbent media is exposed to indoor air to allow laboratories to make necessary calculations.
- ***Air Movement:*** Air must move across the face of the sampler to collect a representative sample. Samplers typically have a recommended range for “face velocity.” Areas with stagnant air flow should be avoided, such as closets, inside shelves and within 6 inches of a wall. Some high UR samplers can be prone to low-biased concentrations in some indoor settings such as a basement with limited ventilation. If air movement is not noticeable on the human skin in the setting to be sampled, the DNR recommends checking air flow velocity with an anemometer of sufficient accuracy to verify that the airflow is above the minimum recommended by the sampler manufacturer (e.g., 15 centimeters per second). One option is to use a small fan to promote some air movement in these situations. Alternatively, a lower UR sampler could be chosen for such locations. High air flow can cause high biased concentrations with some samplers; air flow into the sampler becomes dominated by advection instead of diffusion. When assessing the breathing zone, avoid areas with high air flow such as near air vents, windows and exhaust fans. In some cases, high air flow settings can’t be entirely avoided or there is an interest in evaluating those locations, such as an HVAC duct. Some types of samplers can provide a less biased sample in these settings. Samplers placed close together can compete for contaminants and may result in a low-biased result. A minimum separation of two feet should be maintained between samplers placed in the same room.
- ***Humidity:*** Continuous high humidity settings can affect the UR of some types of sorbents[32] and some polar compounds. Laboratories can partially mitigate the effects of moisture during sample preparations. The DNR recommends choosing a sampler that uses a hydrophobic sorbent or passive permeation membrane for continuously humid settings, such as sub-slab or conduit settings.
- ***Temperature:*** Temperature extremes can cause the UR to deviate from that determined in the laboratory. Avoid locations in direct sunlight, next to an outside wall or near devices that generate heat or cold, such as a space heater, lighting fixture or window air conditioner.

[32] Such as activated carbon used in solvent extracted sorbents.

- ***Non-target Compounds:*** High concentrations of non-target compounds in the air can compete with adsorption of some COCs and give a low-biased result. If high concentrations of non-target compounds are likely in the sampled setting, the DNR recommends discussing this information with the laboratory.
- ***Concentration Range:*** If the UR is too high and the sample duration too long for the concentration, the sorbent may become saturated, causing the sample result to be biased low; however, this is not likely for typical indoor concentration ranges. Pre-screening sample locations with a PID can assist in selecting the appropriate sampling duration or sorbent.
- ***Outdoor air***: Select a sampler appropriate for the location or use a shelter to prevent exposure to sunlight, rain and excessive air flow. Some commercially available shelters can be mounted on poles at a height that helps prevents tampering.

DNR Recommended Steps in Planning and Implementing a Passive Sampling Program

1. **Determine the target COCs.**
2. **Determine the target or available sampling duration.**
    a. Is the period shorter to obtain results more quickly or longer to better account for temporal variability?
    b. Is there a practical time limit due to access permissions?
3. **Determine the reporting limit.** In some cases, passive samplers can be used qualitatively to determine where concentrations are higher, for example, in a hot spot beneath a parking lot. Such applications allow more flexibility in reporting results. Whenever samplers are used to determine whether contaminant concentrations are below a VRSL or VAL at a location for the purpose of evaluating risk to building occupants, the DNR recommends that reporting limits for the COC conform to the guidelines below:
    a. ***Indoor Air:*** Below the VAL for all samples[33]. Longer duration samples should have reporting levels equivalent to or below those typically achieved by canister samples.
    b. ***Sub-slab:*** Below the sub-slab VRSL for all samples[34]. Longer duration samples should have reporting levels equivalent to or below those typically achieved by canister samples.
    c. ***Conduits:***
        i. For conduits that enter a building, at locations outside the building, below the Sanitary Sewer Gas Screening Level. See DNR *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649).
        ii. For conduits within a building, below the VAL.
    d. ***Soil Gas:*** Below the shallow soil gas VRSL.
4. **Determine expected sampling conditions,** for example: humidity, air flow, temperature, anticipated concentration range, presence of non-target compounds, occupant expectations, placement limitations, and the need to account for HVAC setbacks or occupancy levels.
5. **Consult with the laboratory** to select the appropriate sampler and sorbent for the target COCs, setting, anticipated concentrations, and expected sampling duration that can achieve the target reporting limits. For critical contaminant risk drivers (for example TCE, PCE, benzene but others as determined by site specific conditions), choose samplers that have UR experimentally validated for the COC and the duration of the sampling event.

[33] Sampling events performed to quickly evaluate indoor air and sub-slab concentrations are typically conducted over durations of less than 24 hours. If passive samplers are used during such an event, the shorter duration will result in higher achievable reporting limits. The use of a passive sampler is still appropriate (and may be preferred if sampling can be performed more quickly due to canister availability limitations) if the VAL and VRSL can be achieved.

[34] Ibid.

Equation 3. Minimum Sample Duration

$$t = \frac{M_{min}}{UR \times RL}$$

Where: **t** = sample duration time (min)
M_{min} = laboratory reporting limit for each individual VOC in the target list (µg)
UR = uptake rate (mL/min, compound-specific); aka sampling rate (device-specific)
RL = reporting limit

6. **The DNR recommendations for implementing the sampling program.**
   a. Follow all sampler-specific procedures.
   b. Utilize appropriate number of field quality control samples recommended by the lab.
   c. Accurately record the start and stop dates and times the sampler is removed from its container.
   d. Document the sampler placement using a description, sketch, or photograph.
   e. Document temperature during sampling (minimum recommendation) and, humidity and air movement if there is uncertainty about the use of the sampler in the setting being sampled. Measure at the start and end of sampling for locations where these parameters do not vary substantially, such as most residences. In other situations, place a device that records this information, particularly temperature, during the sampling period. The local weather station can provide this information for outdoor settings.
   f. Collect inter-method samples, such as air canister samples, to assist in evaluation of passive sampler accuracy if site conditions are likely to result in the UR to deviate substantially from published values and concentrations cannot be corrected by the lab using other data collected (such as temperature). Unless the duration of the inter-method sample is similar to the passive sampling duration (for example, by collecting sequential 24-hour canister samples or using a GC), the comparison may have limited value.
   g. Provide documentation of sampler manufacturer, sorbent type, extraction and analytical method, reporting limit, equivalent air volume sampled (this is the UR times the duration of sampling), laboratory certifications or accreditations, QA/QC procedures, and sampling conditions as described above.

Real-Time Analysis (RTA)

RTA involves measuring COC concentrations with a device that provides results within minutes. RTA methods may be used to supplement the information derived from laboratory analysis of samples (Wis. Admin. Code § NR 716.13(3)). Devices range from a portable hand-held PID that measures total VOC in parts per million (ppm) to stationary GC/ECD units that either collect samples via long tubing or analyze independently gathered syringe samples to measure individual compounds in the sub-µg/m^3 range. RTA can quickly identify potential sources, assess contaminant pathways, routes of entry into buildings, entire residential neighborhoods, and the effect of building ventilation operations and mitigation measures. A field portable GC/MS may be beneficial in locating preferential routes of vapor entry at buildings[35]. RTA does not typically take the place of canister or passive sampling because the duration of sample collection may not reflect average concentrations over the timeframe for exposure. However, real-time sampling results can help identify acute risk situations and narrow the investigation area. The DNR recommends selecting a device that is suitably calibrated and has detection and reporting limits below the VAL or VRSL for the COC if results are being used to rule out risks. Some of these devices require specialized knowledge to operate. Some devices allow use in a survey mode to locate the areas of highest contamination and then use a data recorder to monitor concentrations over time. The DNR recommends using RTA in complex commercial and industrial buildings and in

[35] Schumacher et al 2021.

situations where quick results from many locations are needed.

If RTA is being used to make time sensitive decisions regarding indoor air concentrations, particularly when TCE is present, the DNR recommends that results and related information (such as calibration results) are quickly communicated to the DNR. The DNR recommends the following information be provided to the DNR:

- **Method summary:** How does the device work? What are the principle uses and limitations (for example, expected precision, concentration working range, impact from non-target compounds, other interferences).
- **References:** Examples of successful use of the device in situations similar to those in the setting being evaluated. These build confidence in the use for the current investigation.
- **Standard Operating Procedure** (SOP) if one is available from the instrument manufacturer, vendor, or sub-contractor.
- **Personnel qualifications:** Document whether sampling technicians meet the minimum qualifications and training for operating the device as recommended by the manufacturer.
- **Reporting limits:** Document what method detection limit and reporting (quantitation) limits are being achieved for each COC for the project. If concentrations of results are being used to make risk decisions as opposed to screening to determine if the COC is present or for locating preferential pathways, reporting limits should be below the VAL for samples collected in indoor air, sumps, interior plumbing conduits, or crawl spaces, below the VRSL for sub-slab or soil gas samples, and below the SSGSL for samples from sanitary sewer main pipes or manholes, for the type of building being assessed and take into account sampling precision.
- **Carryover:** Document what measures are taken to prevent analysis of high concentration samples affecting concentrations of subsequent sample.
- **Sample collection:** A description of how the sample is collected and delivered to the device.
- **Initial calibration:** Procedure and results from calibration of the device prior to use.
- **On-going Quality Assurance and Quality Control:** A description of the procedures and frequency used to check the accuracy of the sampling and analysis, including calibration, field blanks, or duplicates. Include a description of how calibration sample results are used to correct for instrument drift or determine the need for recalibration, and method used for standard preparation.
- **Additional information:** Any relevant information that is specific to the device being used.
- **Data Reporting:** Particularly when DNR review and feedback is desired in a short time frame, present data in a visual manner which quickly communicates results and exposures. Also provide data listed in tabular format.

Active Sorbent Sampling

In active sorbent sampling, air is drawn through a tube containing an adsorbent media using an energized pump. The laboratory analyzes the sorbent material using U.S. EPA Method TO-17 or equivalent. The laboratory then back-calculates average air concentration based on mass adsorbed to the media, the air flow rate of the energized pump, and sample duration (typically between 8 to 24 hours). Breakthrough can occur if the capacity of the adsorptive media is used up, but air continues to be pumped through the device. Breakthrough will result in a calculated time-weighted average concentration that is biased low relative to the actual air contaminant concentrations. The DNR recommends planning carefully when using U.S. EPA Method TO-17 or equivalent to ensure the volume flow rate of air over the sample duration will not cause breakthrough.

Building Pressure Cycling

With BPC, air pressure is increased and decreased, typically with a blower door or box fan, and concentrations and pressure differentials in and around a building are measured. This technique may be used to estimate indoor air concentrations and building contaminant loading rates during periods when conditions are more conducive to VI, without waiting for meteorological conditions that produce these conditions to occur. When both positive and negative pressure cycles are implemented, this method can help differentiate between indoor and external contaminant sources and may indicate whether VI through a conduit pathway plays a significant role.

Buildings with high air leakage are not suited to this method due to the difficulty of establishing and maintaining interior pressure conditions. BPC will impact the building AER during the test, affecting response and interpretation of changes in indoor air concentrations. Evaluating the impact of pressure changes on AER is important for an accurate BPC test.

BPC testing can only assess the response of building conditions exiting at the time of the test. Results from the BPC testing are unlikely to apply if significant changes are made to the building, such as window replacement, or if environmental conditions change including the surrounding ground cover or source concentration.

BPC testing has been applied in numerous investigations; however, best practices are evolving.[36] Building and site conditions, particularly soil texture, will affect how a building responds to BPC.[37] This test requires experience beyond typical indoor air or sub-slab sampling and necessitates disruption to building occupants. Because the higher negative pressures induced during this test are likely to result in elevated indoor air concentrations, the DNR recommends that the test be conducted while the building is unoccupied, and sampling should verify that concentrations are safe prior to re-occupancy,[38] especially if TCE is a possible contaminant. Due to its relative newness, DNR review of a BPC test workplan is recommended prior to implementation.

Recommendations for Special Sampling Situations

Crawl Spaces

Enclosed crawl spaces may provide an opportunity to collect an air sample using sampling methods like those used for indoor air. Some investigations have found higher concentrations in crawl spaces during the summer months.

Elevators

Elevators often have pits extending beneath foundations with unknown sealing and rising elevator cars produce a negative pressure. Consequently, the DNR recommends that elevators be sampled when a location has screened in for a VI field investigation. The DNR recommends placing a long duration passive sampler at the base of the shaft, ideally within the elevator pit, and, at a minimum, collecting indoor air samples within passenger cars or near the elevator doors. Pit and passenger car sampling may be paired for best data analysis.

Parking Garages

Buildings with open air or enclosed, ventilated parking levels warrant a specific sampling strategy. Ventilation to address vehicle exhaust may not be sufficient to prevent chemical VI, particular into spaces outside (accessory spaces) the area where vehicles park. Evaluating the design and operation of the parking garage may assist when designing a sampling strategy. See Sections F2.2.4 and F2.3.4 for information regarding mitigation involving parking garages. For a building with a basement or ground floor parking level, the DNR recommends the following:

[36] Lutes 2022.
[37] Liu 2021 and Yao 2020.
[38] DoD 2017.

- Sub-slab: Collect sub-slab vapor samples (Wis. Admin. Code § NR 716.11(5)(g)).
- Occupied spaces (Wis. Admin. Code § NR 716.11(5)(h)):
  - Parking space: Unless the parking garage is open to outdoor air (i.e., no enclosed exterior walls), collect indoor air samples. Select the sampling method considering the operation of the ventilation system and garage doors and the expected presence of PVOCs. Longer duration sampling events are recommended. If the ventilation system is not continuously operated, collect some samples during lower use periods (i.e., overnight, weekends) when indoor air concentrations may be higher.
  - Auxiliary rooms/areas: Collect indoor air samples in enclosed areas within parking garages, for example stairwells, elevator pits and cars, waiting rooms/lobbies, offices, ticket booths, utility rooms.
  - Occupied rooms on floors immediately above the parking garage: Collect indoor air samples in representative locations.
  - Areas on other floors: Focus on areas near stairwells, elevators, or other potential preferential pathways.

8.5.4 DNR Recommendations for Outdoor Air Sampling

Outdoor air samples help with evaluation of background air concentrations. The DNR recommends taking outdoor air samples anytime indoor air or shallow soil gas samples are collected. The same collection procedures may be used for indoor air samples considering the factors and recommendations below.

Number of Samples: Investigations with evaluation of multiple nearby buildings during the same sampling period do not necessitate outdoor air samples at each building; however, evaluation of initial sample results may prompt further follow-up outdoor air samples during subsequent events. Examples of this are high concentrations in the initial outdoor air sample, or unexplained indoor air concentrations in a particular building. Investigations for large industrial buildings with multiple air intakes, and other similar situations, may need additional samples at the outset.

Sample Location: Set sampling devices upwind and/or near air intakes, near the building(s) undergoing testing, and above the ground surface. Avoid locations near an exhaust opening, such as windows or vent fans.

Sample Security: Samplers should be located where the devices will not be vandalized or disturbed accidentally by pets, children or others.

Relation to Indoor Air Sampling: Initiate collection of outdoor air samples prior to indoor air sampling to account for the time it takes to draw air into an occupied space and over the same duration as indoor air if possible.

Plant Transpiration: Trees can evapotranspire VOCs from shallow soil or groundwater contamination. Avoid locations for outdoor air samples under trees in such situations if possible.

9 Evaluating Vapor Investigation Results

Report vapor sampling results to the DNR, owners and occupants within 10 business days after receiving results (Wis. Admin. Code § NR 716.14(2)). Compare the sampling results to either the VAL or VRSL to determine if concentrations present a risk to current or future users of a building. Evaluate the results for an appropriate immediate or interim response action, as described in Section 10. Delaying an evaluation by waiting until the site investigation is complete could result in ongoing exposures to receptors.

Roles of the DNR and DHS
Both the DNR and DHS are responsible for ensuring that human health is protected at properties with hazardous substance discharges to the environment. For VI, the DNR focuses on determining the nature, degree and extent of contaminated vapor migration and interrupting the vapor pathway. DHS focuses on specific situations where a risk to human health from vapor intrusion is likely, especially for residential settings. The DNR and DHS collaborate closely on VI and are available to assist with risk communications. See Section 4 and Tables 1 and 2 for more on the role of DHS in vapor investigations.

9.1 Background Vapor Sources

The DNR regulates contamination from hazardous substance discharges to the environment and environmental pollution under Wis. Stat. ch. 292. If contaminant concentrations detected are due to sources other than a discharge of a hazardous substance to the environment or environmental pollution, the VI pathway may be ruled out. In this case, although the DNR will not require the RP to act, other regulatory agencies or health officials may require actions.

The DNR recommends limiting the list of analytes reported by the laboratory to the COCs and breakdown products (see Section 8.2.1). For example, dichlorodifluoromethane (DCDFM) in sub-slab vapor may result from polystyrene foamboard being installed during building construction, causing the DCDFM VRSL to be exceeded in sub-slab vapor.

TCE and Women Who Are or May Become Pregnant
If an indoor air source is suspected, usually the next step is to re-inventory and resample indoor air and sub-slab vapor. However, when TCE is a contaminant and women who are or may become pregnant are present, follow steps in Table 1 to reduce exposure risks.

Off-gassing from indoor products or materials can cause VAL exceedances, even after installation and commissioning of a mitigation system (meant to interrupt vapor intrusion sources). When off-gassing causes indoor air contamination, local health agencies may have authority to regulate the contamination[39]; the DNR regulates indoor air contamination due to vapor intrusion from sub-surface contamination[40]. Consultation with the DHS and/or local health departments for health risk communication and/or additional follow-up may be needed.

The sampling recommendations in Section 8 may help with evaluation of whether outdoor air or indoor sources contribute to indoor air concentrations; however, comparing a few sub-slab vapor and indoor air data points may not be sufficient to rule out a VI pathway in cases where indoor air concentrations are elevated and sub-slab vapor concentrations are not. Sub-slab vapor concentrations can vary by orders of magnitude over time and across the slab of even a small building. Differentiating between an indoor air source and a preferential pathway can also be difficult. Some buildings may necessitate additional investigation of sources and routes of entry.

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[39] For example, off-gassing from contaminated building materials or consumer products containing the chemical.
[40] The DNR RR Program regulates investigation and cleanup of the subsurface contamination, including the mitigation system to address sub-slab and conduit vapor intrusion.

9.1.1 *OSHA Regulated Settings*

In general, VALs apply in areas not subject to Occupational Safety and Health Administration (OSHA) standards or alternative guidelines. If the COC is currently being used in a manufacturing or commercial process and OSHA standards or alternative guidelines apply, the DNR recommends providing documentation that demonstrates the indoor air contaminants are related to background operations, not the result of the discharge of a hazardous substance.

Figure 9. VALs applied to property with multiple land uses where no COCs are in use

Figure 10. VALs applied to property with multiple land uses where a COC is in use

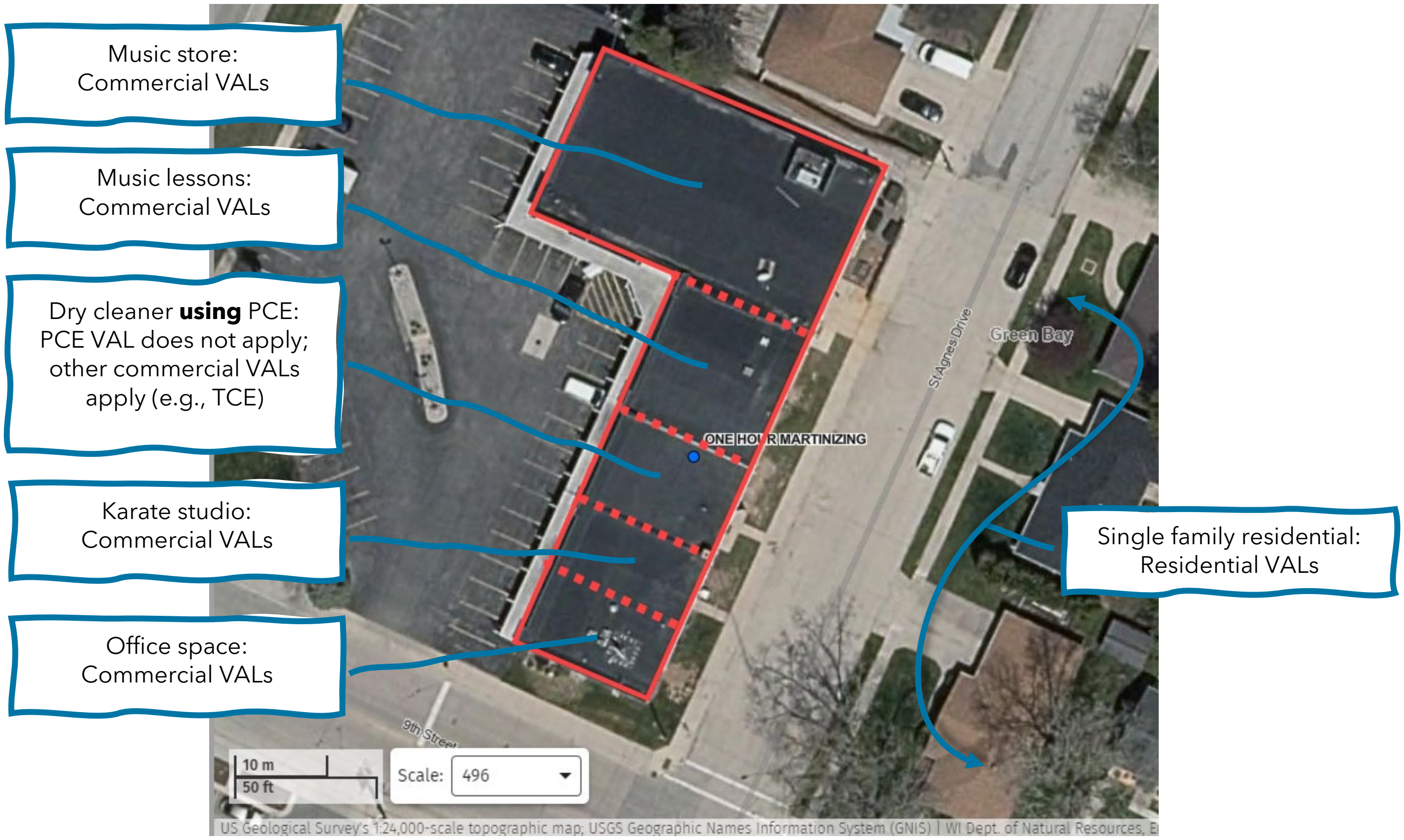


Table 4. Common Household Sources of Background Indoor Air Contamination Listed by Product

NOTE: Analysis of indoor air should be specific to the volatile organic compounds (VOCs) expected from soil and groundwater contamination. (e.g., If chlorinated volatile organic compounds (CVOCs) are the target chemical, then items containing CVOCs should be removed from the building prior to sampling and analysis limited to the contaminants of concern (COCs).

Fuel containers or devices using gasoline, kerosene, fuel oil and products with petroleum distillates:	
• Paint thinner • Oil-based stains and paint • Aerosol or liquid insect pest products	• Mineral spirits • Furniture polishes
Personal care products:	
• Nail polish • Nail polish remover • Colognes and perfumes	• Rubbing alcohol • Hair spray
Dry cleaned clothes, spot removers, fabric/leather cleaners	
Household Cleaners:	
• Oven cleaners • Carpet/upholstery cleaners • Bathroom cleaner/toilet bowl or tank drop-ins	• Appliance cleaner • Citrus (e.g., orange) oil or pine oil cleaners • Furniture/floor polish
PVC cement and primer, various adhesives, contact cement, model cement	
Paint stripper and adhesive (glue) removers	
Degreasers and cleaning solvents, such as:	
• Aerosol penetrating oils • Brake cleaner • Carburetor cleaner	• Commercial solvents • Electronics cleaners • Spray lubricants
Moth balls and moth flakes	
Aerosol spray products:	
• Paints • Cosmetics • Automotive products	• Leather treatments • Pesticides
Deodorizers, air fresheners, scented trees, potpourri, and scented candles	
Hobby supplies	
• Paints and lacquers • Solvents	• Glues • Photo darkroom chemicals

Table 5. Common Household Sources of Background Indoor Air Contamination Listed by Chemical[41,42]

Chemical	Household Sources
Acetone	rubber cement, cleaning fluids, scented candles, nail polish remover
Benzene	automobile exhaust, gasoline, cigarette smoke, scented candles, scatter rugs, carpet glue
Bromomethane	space fumigant
1, 3-Butadiene	automobile exhaust, residential wood combustion
2-Butanone (aka Methyl ethyl ketone or MEK)	automobile exhaust, printing inks, fragrance/flavoring agent in candy and perfume, paint, glue, cleaning agents, cigarette smoke
Chlorobenzene	scented candles, plastic foam insulation, paint products
Chloroethane	refrigerant
Chloroform	generated from chlorinated water (showers)
Cyclohexane	gasoline, paint thinner, paint and varnish remover
1,4-Dichlorobenzene	moth balls, general insecticide in farming, air deodorant, toilet disinfectant/drop-in
Dichlorodifluoromethane	refrigerant (CFCs), cleaning solvent, polystyrene foamboard insulation
1, 1-Dichloroethane	plastic products (food and other packaging material), flame-retardant fabrics
1,2-Dichloroethane	molded plastic objects/decorations (particularly from China), cigarette smoke, PVC, vinyl floor adhesives[43]
1, 3-Dichloropropene	fungicides
Ethylbenzene	paint, paint thinners, insecticides, wood office furniture, scented candles, gasoline
Formaldehyde	building materials (particle board), furniture, insulation, cigarette smoke
n-Heptane	gasoline, nail polishes, wood office furniture, petroleum products
n-Hexane	gasoline, rubber cement, typing correction fluid, aerosols in perfumes
Methylene chloride	hairspray, paint stripper, rug cleaners, insecticides, furniture polish
Methyl isobutyl ketone (MIBK)	paints, varnishes, dry cleaning preparations, naturally found in oranges, grapes, vinegar
Methyl *tert* butyl ether (MTBE)	gasoline (oxygenating agent)
Naphthalene	cigarette smoke, automobile exhaust, residential wood combustion, insecticides, moth balls
Styrene	cigarette smoke, automobile exhaust, fiberglass, rubber, and epoxy adhesives, occurs naturally in various fruits, vegetables, nuts, meats
Tertiary butyl alcohol (TBA)	gasoline (oxygenating agent)
1,1,2,2-Tetrachloroethane	solvent, paint and rust removers, varnishes, lacquers
Tetrachloroethylene (PCE)	dry cleaning, metal degreasing, adhesives and glues, insecticides, scented candles, rug cleaner
Toluene	gasoline, automobile exhaust, polishes, nail polish, synthetic fragrances, paint, scented candles, paint thinner, adhesives, cigarette smoke
1,1,1-Trichloroethane (1,1,1-TCA)	spot cleaner, glues, insecticides, drain cleaners, shoe polish
Trichloroethylene (TCE)	glues, adhesives, paint removers, spot removers, rug cleaning fluids, paints, metal cleaners, automotive cleaning and degreasing products
1,2,4 and 1,3,5 -Trimethylbenzene	gasoline, automobile exhaust
Xylenes, total	water sealer, gasoline, automobile exhaust, markers, paint, floor polish, cigarette smoke

[41] DOD. 2009.
[42] New Jersey Department of Environmental Protection 2016
[43] Kurtz, J.P. et al. 2010.

9.2 Vapor Action Level: Compared to Indoor Air Concentrations

VALs are based on U.S. EPA's risk values for human exposure to contaminants in indoor air. The VISL Calculator and *Guidance: Wisconsin Vapor Quick Look-Up Table, Indoor Air Vapor Action Levels and Vapor Risk Screening Levels* (RR-0136) may be used to apply Wisconsin's input values in the VISL Calculator. Find RR-0136 at dnr.wi.gov, search "RR-0136." Wisconsin defines VAL from the U.S. EPA tables using the following criteria:

- Use the HI of 1.0 or 10^{-5} excess lifetime cancer risk, whichever is smaller (Wis. Admin. Code § NR 700.03(66p)).
- Use Residential Air exposure scenario table for a residential setting, which includes child and elder care facilities and schools (Wis. Admin. Code § NR 700.03(49g)).
- Use Composite Worker Air exposure scenario table for non-residential setting, which excludes child and elder care facilities and schools (Wis. Admin. Code § NR 700.03(39m)).
- In mixed-use settings:
  - For sub-slab vapor, use VRSL based on Residential Air.
  - For indoor air, use Composite Worker Air for non-residential spaces and Residential Air for residential spaces.

Compare sample results to VAL when collecting samples from the following locations in occupied buildings:

- Crawl spaces;
- Sumps;
- In front of p-traps, on the building side;
- Within conduits with direct connection to indoor air (e.g., floor drains with no p-trap);
- Shallow soil gas beneath a dirt floor; and
- Sub-slab vapor where the foundation is incompetent and little to no attenuation is expected (e.g., brick floor, degraded or broken concrete slab).

Investigating VI includes collecting air and vapor samples from a variety of locations. The table below summarizes the more common locations and suggested nomenclature for sample locations. The DNR encourages discussing site-specific concerns with the DNR project manager (e.g., dried out p-traps, contaminants of concern in use within an occupied building).

Table 6. Vapor Action/Vapor Risk Screening Level, Attenuation Factors and Sample Nomenclature

Sample Location	VAL or VRSL	AF	Suggested Sample Nomenclature	Additional Comments
Outdoor/Indoor Air & Soil Gas				
Outdoor Air	N/A	N/A – no attenuation	**OA**-# or Location (e.g., OA-1 or OA-West)	Typically background outdoor air samples. Sample concurrent with indoor air.
Indoor Air (see Sections 9.2 and 9.3.3)	VAL	N/A – no attenuation	**IA**-# or Location (e.g., IA-1 or IA-break room)	Including basements and crawl spaces.
Sub-Slab Vapor (beneath the foundation, see Section 9.3.4)	VRSL	0.03* / 0.01**	**SSV**-#	Includes vapor samples directly beneath a slab or membrane.
Soil Gas (see Section 9.3.5)	VRSL	0.03* / 0.01**	**SG**-# (e.g., SG-1, SG-2)	
Sump (temporarily sealed for sample, see Section 9.2)	VAL	N/A – no attenuation	**Sump-**# or Location (e.g., Sump-1 or Sump-North)	
Conduit Vapor				
Floor Drain (behind p-trap)	Varies	Varies	**FD**-# or Location (e.g., FD-paint room)	
Lateral/Plumbing cleanout Gas (behind p-trap)	Varies	Varies	**LPG**-Location	
Sanitary Sewer Gas (within utility main, see Section 9.3.7)	SSGSL	0.03	**SSG**-Location (e.g., SSG-MH-149 for manhole #149)	

* Residential use or small commercial building.
** Large commercial or industrial building.

9.3 Default Attenuation Factors

The DNR recommends using default AFs to estimate the potential for VI based on sample results from other media. Wisconsin allows the use of the default AFs listed in Tables 6 and 8 to calculate VRSLs in most cases (Wis. Admin. Code § NR 700.03(1s)). The AFs are grouped by building use and size.

Factors that may make a building more susceptible to VI where default AFs may not be applicable include[44]:

- Significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations.
- Buildings with deteriorating basements or dirt floors that generally provide poor barriers to soil gas entry.

The DNR recommends observing and considering building conditions to determine the applicable AF.

[44] U.S. EPA 2015.

9.3.1 Residential and Small Commercial

Default AFs for sub-slab vapor, soil gas, and groundwater for residential and small commercial buildings are from the U.S. EPA's VI guidance[45] and are derived from a large database of AFs measured in residential buildings in primarily cold-weather climates.

9.3.2 Large Commercial and Industrial

The U.S. EPA has not defined default AFs for large commercial and industrial buildings; however, Wisconsin allows the use of a smaller default AF for sub-slab vapor for large commercial and industrial buildings that meet certain recommended guidelines because more dilution and mixing of indoor air are expected in these types of buildings. The DNR recommends documenting building features that support use of the large commercial/industrial AF.

The DNR recommends maintaining any building features used to justify the use of lower AFs if sub-slab vapor concentrations are likely to remain above VRSLs. If concentrations persist above VRSLs at closure, maintaining these building features may become part of the CO for the property (Wis. Admin. Code § NR 726.15(2)(h) and (m)). Buildings with multiple uses (e.g., manufacturing building with offices) may fall into more than one category. Evaluate the features as shown below in Table 7.

Table 7. Features Supportive of Using a Large Commercial/Industrial AF

Feature	Supportive of a large commercial/industrial AF
Condition of the foundation slab and walls	Thicker, competent foundation slabs and walls in good condition, typically slabs ≥ 6 inches
Volume of the interior space	Larger rooms with higher ceilings that allow for more air mixing, typically ≥ 25,000 sf footprint and ≥ 10-foot-high ceilings
HVAC	Well managed systems that provide high AER ≥ 4 per hour and/or positive building pressure
Building openings	Large bay doors routinely utilized during occupied times that allow significant ventilation
Interior space	Space is not divided by interior walls, such as offices, meeting rooms, cubicles, restrooms with active vents where vapors could accumulate

9.3.3 Crawl Spaces

The movement of air from a crawl space to an occupied space resembles air movement between floors of a building, making attenuation or dilution unlikely. The default AF for air sampled within a crawl space is 1; therefore, crawl space air data is compared directly to applicable VALs. If crawl space air exceeds VALs, an interim action is required to protect public health (Wis. Admin. Code § NR 708.11). The type of interim action depends on the flooring and construction of the crawl space. Immediate action[46] is required for crawl space air that presents an acute risk[47] (Wis. Admin. Code § NR 708.05).

9.3.4 Sub-slab Vapor

The U.S. EPA recommends a default AF of 0.03 for sub-slab vapor for residential buildings.[48] The DNR

[45] U.S. EPA 2015.
[46] For example, increased ventilation, temporary air purification units, or temporary relocation.
[47] For example, if TCE is above the VAL and women who are or may become pregnant are present; TCE or PCE is above three times the VAL; or naphthalene is above ten times the VAL.
[48] U.S. EPA 2015.

also allows this default AF to be applied to small commercial buildings. U.S. EPA has not defined default AFs for sub-slab vapor for large commercial and industrial buildings; however, the DNR allows the use of a smaller 0.01 default AF sub-slab for large commercial and industrial buildings that meet certain guidelines. See Section 9.3.2.

VRSLs calculated using the applicable AF may be used to evaluate concentrations of soil gas collected immediately below a foundation slab or vapor membrane (i.e., sub-membrane vapor). Concentrations above VRSLs indicate the building could be a risk for VI and an interim action may be required to protect public health (Wis. Admin. Code § NR 708.11). Once a sub-slab VRSL is exceeded, additional testing may be helpful for design of a VMS; however, additional sub-slab vapor testing does not rule out the need for mitigation.

9.3.5 "Near Source" Exterior Soil Gas

The U.S. EPA recommends a default AF of 0.03 for "near-source" exterior soil gas for residential buildings.[49] The calculated VRSL may be used to evaluate soil gas concentrations collected beyond a building envelope. Concentrations above the calculated VRSL indicate potential risk at nearby buildings; however, given the variability of soil gas concentrations and the distance of sample collection from a building, the DNR does not recommend using default AFs for exterior soil gas samples to rule-out the need for investigation of a building without other significant LOEs.

9.3.6 Groundwater

The U.S. EPA recommends a default AF of 0.001 for groundwater for residential buildings unless site-specific conditions indicate that the use of the default[50] is not warranted. (see Section 9.3.1 and Figure 2). Equation 1 uses this default AF for the purpose of screening whether to further evaluate a building, typically by collecting sub-slab vapor and indoor air data. The U.S. EPA has not defined default AFs for groundwater for large commercial and industrial buildings; however, the DNR allows the use of a smaller default AF for large commercial and industrial buildings that meet certain guidelines (see Section 9.3.2).

9.3.7 Sanitary Sewer Gas

A 2018 final report[51] on sewers and utility tunnels as preferential pathways recommends an AF of 0.03 for sanitary sewer mains. See *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649) for more information; go to dnr.wi.gov, search "RR-649."

Table 8. Recommended Default Attenuation Factors

Media	Residential and Small Commercial	Large Commercial and Industrial
Crawl Space	1	1
Sub-slab Vapor	0.03	0.01
Soil Gas	0.03	0.01
Groundwater in contact with foundation*	0.1	0.03
Groundwater ≤ 5 ft from foundation*	0.01	0.003
Groundwater > 5 ft from foundation*	0.001	0.0003
Sanitary Sewer Gas (from Main)	0.03	0.03

*Use of the AF for groundwater for PCE or TCE is not recommended (see Table 2).

[49] U.S. EPA 2015.
[50] U.S. EPA 2015.
[51] DOD 2018.

9.4 VRSL: Compared to Subsurface Concentrations

VRSLs are used to estimate if the concentrations detected in subsurface samples have the potential to produce indoor air concentrations over VALs (Wis. Admin. Code § 700.03(66w)). The AF estimates how much the concentration in the subsurface is expected to decrease (i.e., attenuate) before reaching indoor air (Wis. Admin. Code § NR 700.03(1s)). This estimated decrease depends on the sample location and building type.

Equation 4. Vapor Risk Screening Level

$$VRSL = \frac{\text{VAL}}{\text{AF}}$$

Where: **VRSL** = Vapor Risk Screening Level
VAL = Vapor Action Level
AF = Attenuation Factor

Sites with Multiple Contaminants
When multiple contaminants are present in indoor air, the total risk (i.e., additive risk of each of the contaminants) may not exceed a HI of 1.0, and the cumulative excess lifetime cancer risk cannot exceed 10^{-5} (Wis. Admin. Code § 700.03(66p)). Even if no individual COC exceeds a VRSL, the cumulative risk may not be protective. If more than one COC is present in indoor air, consult with the DHS on the appropriate method to calculate the total risk, unless mitigation is clearly warranted based on one COC.

9.5 Vapor Action Level and Vapor Risk Screening Level Summary Table

Indoor air VALs may apply for either residential or non-residential[52] and AFs may apply for all residential/small commercial and any large commercial/industrial meeting the guidelines in Section 9.3.2. Three different sets of values may apply for each contaminant. DNR *Guidance: Wisconsin Vapor Quick Look-Up Table, Indoor Air Vapor Action Levels and Vapor Risk Screening Levels* (RR-0136) summarizes the VAL for only the most common contaminants in Wisconsin and includes AFs and VRSLs calculated using Wisconsin input parameters for HI and target cancer risk. Locate it at dnr.wi.gov, search "RR-0136."

This *Wisconsin Vapor Quick Look-Up Table* is limited to contaminants that are commonly encountered at cleanup sites in Wisconsin and does not include all contaminants posing a VI risk. If a contaminant is not listed, refer to the U.S. EPA VISL calculator using instructions provided in the *Wisconsin Vapor Quick Look-Up Table*.

9.6 Site Specific Building AF

The purpose of calculating a site-specific AF (SSAF) is to avoid unnecessary installation and maintenance of a VMS when existing building construction provides adequate protection and more attenuation than the default AF. These types of scenarios are rare and are generally limited to newer, large industrial buildings with a uniform, competent 12-inch concrete slab. Calculating an SSAF necessitates enough samples to account for temporal and spatial variability in both sub-slab vapor and indoor air concentrations, especially for larger structures with complicated air handling systems, variable foundations, and many potential preferential pathways.

SSAF are typically calculated based on tracer tests, usually for radon. Radon can be a useful indicator of VI; however, some investigations indicate different behavior of radon in a building compared to the chemical contaminant[53]. Although radon enters a building in much the same way that chemical vapors do, there are significant differences in the conceptual pathway model that raise questions about using radon as a surrogate in calculation of a SSAF. These important differences include location of the source, source variability, half-life in indoor air and movement through the conduit. Although many studies have proposed default AFs based on radon, few have quantitatively compared radon and VOC attenuation with a detailed data set for each. There can be distinct differences between radon and VOC attenuation. Therefore, while using radon as an indicator

[52] Composite worker (commercial or industrial).
[53] Lutes 2019.

of soil gas movement into a structure can be useful, the DNR does not recommend using radon as a quantitative metric for VI risk evaluation or to calculate a site-specific attenuation factor[54].

Future changes to building occupancy, use and the integrity of the foundation could affect indoor air concentrations. Factors including leakance, AER and foundation competence, are difficult to document during the investigation and even more difficult to monitor over the long term. COs may be applied that require the owner to maintain existing features present (Wis. Admin. Code § NR 726.15(2)(m)). These COs assure protectiveness and apply when the DNR approves an SSAF and resulting site-specific VRSL (e.g., maintaining a specific AER, other building settings or integrity of existing foundations). Maintaining these features may be far more cumbersome than maintaining a VMS. Also, SSAF and corresponding site-specific VRSL apply at commercial and industrial buildings; these types of buildings often have preferential pathways and TCE vapor contamination from a sub-slab soil contamination source. These factors add uncertainty when assessing risk. For these reasons, the DNR strongly discourages calculation of an SSAF that is less conservative than the default AF.

In limited situations an SSAF may be more appropriate, for example with relatively low contaminant concentrations, challenging site conditions for installation of a VMS and no acute risk. The DNR recommends submitting a workplan with the appropriate technical assistance fee to the DNR prior to starting work to calculate an SSAF and site-specific VRSL. Calculating an SSAF may be inappropriate for residential and small commercial buildings because foundations are typically of average thickness and management of indoor air is rarely consistently accomplished.

[54] Guo 2022.

10 Response Actions for Vapor Intrusion

After obtaining initial vapor sample results, compare the results to the appropriate VAL or VRSL. Next, determine the timing of follow-up sampling events and whether response actions are necessary. When a vapor sample concentration attains or is over a VAL or a VRSL, and VI is a risk to building occupants, appropriate response actions must be taken to comply with Wis. Stat. § 292.11(3) and Wis. Admin. Code chs. NR 700-799.

Notification of Sample Results
The RP must notify the DNR, property owners and occupants of sample results within 10 business days, unless an alternate timeline is approved by the DNR (Wis. Admin. Code § NR 716.14(2)-(3)).

Responses fall into three main categories:

a. Immediate actions (Wis. Admin. Code § NR 708.05);
b. Interim actions, *i.e.,* mitigation (Wis. Admin. Code § NR 708.11); and
c. Remediation (Wis. Admin. Code chs. NR 722, 724 and 726).

The timing of response actions depends on factors such as concentrations of contaminants in sub-slab and indoor air, occupancy and land use setting; recommendations are included in Table 2, which includes decision matrices incorporating the following factors:

Sub-slab vapor concentrations: Sub-slab vapor concentrations primarily determine the response actions for VI. Regardless of current indoor air concentrations, sub-slab vapor concentrations above the VRSL indicate that the contaminant has migrated to the foundation of the building and the potential for VI exists. Mitigation is required to interrupt the pathway and remediation to reduce the mass and concentration (Wis. Admin. Code § NR 726.05(8)(b)).

Indoor air concentrations: Concentrations in indoor air determine whether a current risk requires immediate action (Wis. Admin. Code § NR 708.05). Indoor air sampling is also used to evaluate preferential pathways.

Follow-up sampling: The DNR recommends follow-up sampling events during periods when RME conditions are likely to gather additional data. This conservative approach partially offsets imprecision in estimates of long duration exposures based on short assessment periods with few samples.

Conduits: See Section 10.3.

The DNR recommends considering all LOE (see Section A3) when deciding whether to collect additional sampling or to implement vapor mitigation. The DNR recommends documenting building decisions and rationales and including them in the site investigation report. Appendix G lists the required deliverables for any immediate or interim actions.

10.1 Immediate Actions

RPs must take immediate actions if there is an imminent threat to public health (Wis. Admin. Code § NR 708.05(2)), including an acute health risk. Immediate actions applicable to acute health risk from inhalation may include increasing ventilation, deploying temporary air purification units, limiting occupancy, temporarily relocating occupants or other actions. Immediate actions may be selected in consultation with the DHS and the local health department. See Table 2, Section F2.2.1 and Appendix H for timing and response recommendations.

10.2 Interim Actions - Vapor Mitigation

Vapor mitigation is generally an interim action and may be required even when the site investigation is not complete when sub-slab concentrations are at or over VRSLs (Wis. Admin. Code § NR 708.11). Installation of a SSDS is the most common mitigation strategy (See Appendix F).

10.3 Responses for Conduit Vapor

Best practices for investigating and evaluating concentration data and responding to vapor entry via building conduits are evolving. Indoor air concentrations may reflect contributions entering from both foundation cracks and conduits. Standard sub-slab mitigation techniques are unlikely to interrupt the conduit pathway; therefore, addressing conduits is likely to require additional measures. If the investigation reveals that contaminant vapor from the source area is moving within conduits into occupied spaces and causing a VAL exceedance, the RP may be required to take immediate or interim actions (Wis. Admin. Code § NR 708.01). The DNR recommends taking these actions within the same time frames in Table 2 for foundation crack entry scenarios. See Section F2.2.5 for recommendations to reduce contributions from conduits.

Mitigation and Closure
Mitigation of the vapor pathway is a criterion for case closure for occupied buildings where subsurface vapor conditions attain or exceed a VRSL (Wis. Admin. Code § NR 726.05(8)(b)(2)). Where sub-slab vapor concentrations attain or exceed a VRSL, the steps taken to remediate the source of vapors to the extent practicable, and to interrupt and mitigate the vapor exposure pathway must be demonstrated (Wis. Admin. Code § NR 726.05(8)).

Vapor concentrations above the VAL in conduits within the building present a potential risk, even if p-traps currently prevent intrusion of vapors into occupied spaces. If p-traps fail or other breaches occur[55] indoor air quality can deteriorate rapidly. CVOCs pose a risk at concentrations well below odor thresholds; therefore, occupants are unlikely to notice these breaches. This situation is similar to buildings where vapor concentrations are above the VRSL in sub-slab samples, but indoor concentrations are below the VAL. Mitigation is required due to the *potential* risk to meet the closure criteria (Wis. Admin. Code § NR 726.05(6)(d)); therefore, the DNR may impose a CO to maintain mitigation that interrupts VI via conduits (Wis. Admin. Code § NR 726.15(2)(m)).

If a conduit trap fails or other breach occurs, many factors can affect whether a VAL exceedance in indoor air occurs, including:

- **a.** The concentration of contaminants within the conduit;
- **b.** The rate of movement of vapor from the conduit into indoor air, based primarily on the air pressure difference between the conduit and indoor air;
- **c.** The AER of the building; and
- **d.** How freely vapors move from the source through the conduit in response to indoor air. This factor depends on the proximity of the source, and whether diffusion limits the rate of movement along the path[56] or the conduit contains a continuous liquid source.

Some dilution of contaminated vapors from conduit moving into indoor air can be expected. However, a few sampling events are unlikely to capture the highest possible concentrations due to the variability in conduit vapor. The U.S. EPA has not yet recommended AFs for evaluating conduit concentrations within a building. The DNR recommends making mitigation decisions on a case-by-case basis following the guidelines below.

[55] For example, a p-trap may dry out and fail, or other breaches may occur, such as a crack in a stack vent.
[56] For example, if the source is contaminated bedding material along a sanitary sewer lateral.

Table 9. Recommendations for Conduit Vapor

Contaminant Concentration in Conduit Protected by a Functioning P-Trap or Pipe[57]	Recommendation
< VAL	Once sampling is complete, no further vapor-related actions are necessary for this pathway.
Between VAL and 10X VAL	Check the integrity of all traps and vent pipes. Consider performing a smoke test to check the integrity of plumbing system or BPC. Evaluate the need for additional mitigation on a case-by-case basis.
> 10X VAL	When the concentration of the COC greatly exceeds the VAL within the conduit, the potential for an exceedance of the VAL in indoor air increases if the conduit is compromised. The DNR recommends additional conduit mitigation measures such as pipe ventilation, and/or installation of special valves or traps.

Mitigation measures may interrupt this pathway in the near-term; however, the DNR recommends evaluating remediation of the contaminant source if it is resulting in high vapor concentrations in conduits within buildings. See DNR publication *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors* (RR-649) for remedial options; available at dnr.wi.gov, search "RR-649."

10.4 Future Vapor Risk – Existing Building

The DNR cannot close a case if the remaining level of contamination is likely to cause a VAL to be attained or exceeded in the future (Wis. Admin. Code §§ NR 726.05(4)(a), (e) and NR 726.05(6)(d)). Changes to the setting in and around a building may increase vapor concentrations in the occupied spaces, even if source concentrations remain stable or even decline. Some changes may be estimated through modelling; however, the DNR discourages relying on modelling to predict future conditions. See Section A4.10.

Factors not Addressed by COs
While some COs can limit activities or changes on a property, some activities may be unreasonable to impose as COs, such as restrictions from paving a gravel driveway or installing energy efficient windows which may increase the potential for VI.

Consider the factors below when selecting response actions for existing buildings with occupied spaces.

10.4.1 Surface features

Surface conditions surrounding a building affect vapor concentrations in the subsurface and in gas that enters through foundation openings. If the land surface around a structure is largely open (i.e., uncovered), testing conducted during a VI field investigation may not identify a VI concern; however, paving the surface around the building may result in future VAL and/or VRSL exceedances. The DNR recommends considering the land surface within 150 feet of the building and the likelihood that open areas will be paved as a LOE.

10.4.2 Building Structure and Operation

Changes to the building structure and use may increase vapor flux into the building[58] or reduce

[57] This table does not apply to samples collected in conduits that are not protected by p-traps (e.g., an unsealed sump). If an unsealed sump is sealed temporarily to collect a sample and the concentration is above the VAL, treat it as an indoor air sample; mitigation should include sealing and venting the sump.
[58] See Qsoil in Figure A-3.

dilution. Such changes include foundation material deterioration[59], added preferential pathways[60], or changes affecting the AER[61]. Some factors may be evaluated with a BPC assessment. Older houses are likely to have higher AER and are more susceptible to higher contaminant vapor concentrations if weatherized. Some operational or structural changes can also impact VI in mitigated structures.

The American National Standards Institute / American Association of Radon Scientists & Technologists (ANSI/AARST) standards[62] for mitigation of single-family homes include recommendations for situations where building changes or natural changes prompt additional monitoring.

10.4.3 Water Table

Variations in vapor concentrations at the base of a building partially reflect the effect of variations in water table elevation and may be observed with sampling over a sufficient period. A significant change in water table elevation (e.g., from meteorological conditions or pumping) could cause vapor concentrations to rise and fall. The effects are difficult to predict; fluctuations in the water table elevation typically have less effect on vapor concentrations when the water table is deeper, with a greater lag time for effects to occur. The DNR recommends selecting a more conservative mitigation strategy if there is an indication that the water table level is fluctuating. See Sections A3.3 and A4.10 for additional information.

10.4.4 Climatic Factors

Studies that measured vapor concentrations at houses over multiple years found that concentrations varied significantly from year to year. The DNR recommends comparing climate data from the sampling period, primarily temperature and precipitation, to seasonal averages to assess under what conditions samples were collected. If the sampling period is not representative of worst-case climatic conditions[63] for VI, a more conservative mitigation strategy may be warranted. In addition, warmer soil conditions or a change in geochemical conditions could increase vapor concentrations or facilitate an increase in concentrations of more toxic compounds (e.g., degradation of PCE to TCE).

10.5 Remediation of Vapor Source

Remediation of the vapor source is the most effective way to eliminate long-term risks of VI from contaminated soils, groundwater, and/or NAPL. A remedial action options evaluation must be performed under Wis. Admin. Code ch. NR 722 and the evaluation used to select a remedial action under Wis. Admin. Code ch. NR 724. In general, remedial action options must be evaluated based on factors relating to technical and economic feasibility. (Wis. Admin. Code § NR 722.07(4)).

The DNR cannot close a case if the remaining level of contamination is likely to cause a VAL to be attained or exceeded in the future (Wis. Admin. Code §§ NR 726.05(4)(a), (e) and NR 726.05(6)(d)). Therefore, remedial actions must

Remediation Required for VRSL Exceedances
When concentrations exceed a VRSL, remediation is required to reduce the mass and concentration of the vapor source to the extent practicable (Wis. Admin. Code § NR 726.05(8)(b)1.). A VMS is not considered a remedial action; it serves to interrupt the vapor pathway but does not address the contaminant mass or concentration.

[59] For example, drying or cracking of concrete.
[60] For example, new utility penetrations.
[61] For example, HVAC system changes, weatherization for energy efficiency, occupant use, and addition of mechanical ventilation.
[62] ANSI/AARST standards https://standards.aarst.org.
[63] For example, the winter was abnormally warm.

address contaminants[64] that enter occupied spaces through all pathways including conduits (Wis. Admin. Code §§ NR 726.05(4)(e), (8)). See Sections 10.4 and A4.10.

10.6 Mitigation Prior to Case Closure - New Construction or Building Modifications

10.6.1 New Construction

If construction of a new building or expansion of an existing building is planned in an area that screens in for vapor risk using the guidelines in Figures 2 or 3, the new building or expansion has potential risk of VI and **the DNR recommends incorporating vapor mitigation features during construction.** This approach is often more cost effective and less intrusive than trying to retrofit a VMS after construction. See Appendix F for recommendations and the ANSI/AARST standards[65] for information on mitigation design for new construction and building modifications. At sites with CVOC contamination, the DNR recommends including active mitigation elements in the design. Including sub-slab vapor sampling ports during construction will facilitate collection of sub-slab vapor samples. The DNR recommends that these vapor sampling ports be designed to measure the highest concentrations existing beneath the slab[66] and assess the relevant pressure differentials[67] as needed to confirm the effectiveness of the system. These ports should be designed to maintain the integrity of any chemical vapor barrier installed during construction.

VI Considerations for New Construction
A VMS may be incorporated into construction of a new building; however, there will still be uncertainty about post-construction vapor conditions. The DNR recommends the following:

- Involve the DNR early
- Use passive soil gas sampling to characterize concentrations within the future building footprint prior to construction
- Conduct remediation to reduce the mass and concentration of the source prior to development
- Hire an environmental consultant to oversee construction contractors during construction
- Address preferential VI routes into the building
- Allow ample time for the DNR to review design plans
- Allow ample time for VI field investigation, mitigation and commissioning activities in the development schedule (prior to occupancy)

Post Construction Sub-Slab Vapor Sampling

If a building is constructed before a site has reached case closure under Wis. Admin. Code ch. NR 726, an evaluation of the presence and concentration of vapors sub-slab and in indoor air may be required (Wis. Admin. Code §§ NR 716.11(5)(g) and (h)). The DNR recommends collecting sub-slab vapor, indoor air, and, if applicable, conduit samples from representative locations after construction is complete. This is consistent with the recommendations in Section 8 and Figure 4. If elements of a VMS are incorporated in the building design as described above, results from the post-construction sub-slab vapor sampling along with other LOEs will inform on whether operation of a VMS is required or voluntary and whether it is recommended that a passive system is made active. If elements of a VMS were not incorporated, the decision of whether a VMS is required is based on the same factors as an existing building and installation of a VMS is likely to be more expensive.

Conditions Unique to New Construction

In new buildings it can take weeks or months for vapor concentrations beneath the slab to reach

[64] Natural attenuation is unlikely to be a sufficient remedial action for recalcitrant contaminants such as CVOCs that persist for many decades and continue to be a source for VI.
[65] https://standards.aarst.org.
[66] Typically, near the center of the slab and away from the effects of ambient air.
[67] Typically, sub-slab to indoor air.

pseudo-equilibrium[68], depending on the setting. Adding adjacent buildings or other features like driveways, can lengthen this period. Unmitigated vapor concentrations primarily determine whether a VMS is required. Once the VMS is operational, intrusion of atmospheric air is likely to affect sub-slab vapor concentrations such that samples collected with a VMS operating do not reflect unmitigated vapor concentrations. A common approach for new construction is to install a basal granular layer beneath a chemically resistant membrane with a pipe network connected to a riser that vents passively. Even when the risers of a passive system are blocked, this type of construction is likely to affect sub-slab concentrations. Given these circumstances, the DNR may place a CO for maintenance of the system passively, even if the sub-slab vapor concentrations are less than the VRSL, if other LOEs suggest that a VI risk to the building exists (Wis. Admin. Code § NR 726.15(2)(m)). Given the potential risk of allowing contaminants or methane to enter the occupied space of the building through the foundation even when elements of a VMS have been installed, DNR does not recommend capping passive venting features. If the location and concentration of the soil or groundwater source means that sub-slab vapor concentrations are likely to exceed VRSL, the simplest approach may be to collect an initial round of sub-slab vapor samples and then activate the system.

Timing of Sample Collection

The DNR recommends collecting initial sub-slab vapor samples as soon as possible after construction is completed. This sample may not be representative of pseudo-equilibrium conditions; however, if results are above the VRSL, focus may be shifted to activating and commissioning the VMS. Alternatively, if concentrations are below the VRSL, activate the system or proceed with assessment sampling. Passive sample results collected within the footprint of the future building, while not representative of concentrations that will exist after completion and operation of the building, may be sufficient to indicate that operation of an active VMS is needed to protect building occupants. Pre-construction passive soil gas sampling may also reveal the presence of compounds not found in discrete soil or groundwater samples.

System Operation

If the blowers or fans of a VMS are activated prior to completing a standard vapor sampling program, the DNR recommends completing the mitigation design, performance verification testing, and long-term OM&M plan to demonstrate protection from the VI pathway (see Appendix F). At buildings where TCE is a contaminant or high concentrations of other COCs are present (i.e., greater than three or ten times the VRSL for non-carcinogens or carcinogens, respectively), the DNR recommends operating an active VMS prior to occupancy to address any exposures to occupants over shorter periods of time.

[68] This term is used to denote that vapor concentrations are always dynamic, even for an existing building.

10.7 Mitigation after Case Closure - New Construction or Building Modifications

Historical Changes to VI Assessment and Closure
The DNR published guidance on investigation of vapor intrusion in 2010 and mitigation in 2018. Rule revisions took effect in 2013 that included CO options for VI.

Prior to the guidance being published in 2010, site investigations were unlikely to assess VI and closure letters were unlikely to include COs for VI issues.

After 2010, VI was more likely to have been assessed as part of the site investigation, and COs related to VI were more common in closure letters. Vapor-related COs became more common after 2013.

When a case is closed under Wis. Admin. Code ch. NR 726, any actions at the site must comply with the conditions of the closure letter (Wis. Admin. Code § NR 727.05(1)(a)).

Sites where VI was not evaluated as part of the site investigation may still pose a risk from VI. The DNR recommends considering mitigation best management practices (Appendix F) for any existing or new buildings within the screening distances (see Sections 2.4 and 2.5) of remaining contamination.

Language in DNR closure letters changed over time. **Contact the DNR to discuss requirements versus recommendations based on the site-specific closure letter.** For many sites, the DNR granted closure based on the condition that the property owner provide advance notice to the DNR and include vapor control technologies when constructing or modifying occupied buildings, unless a vapor pathway assessment indicates, and the DNR agrees that vapor control technologies are not needed. If an assessment is performed, the DNR recommends that it be consistent with this guidance. The results from the post-construction or building modification sub-slab vapor sampling will help guide whether vapor mitigation is required or voluntary, considering the decision guidelines in Table 2. See Section 13 for additional information on post closure modifications related to VI.

Ensuring that vapor barriers and passive systems will protect public health long-term is fraught, difficult and expensive. The DNR strongly recommends using an active mitigation system for protection from residual CVOCs. The DNR recommends that all new construction follow the ANSI/AARST standards developed by radon and soil gas mitigation professionals (see Section F2.2). If mitigation is required for protection of human health from potential VI, the DNR may require documentation that the system is protective (e.g. performance verification testing). In addition, a long-term OM&M plan (Appendix F) and CO to verify effectiveness and ensure long-term protection from VI, may be required depending on the site-specific closure conditions (Wis. Admin. Code § NR 726.05(6)(d)).

11 Mitigation Design

Vapor mitigation involves engineered systems that interrupt the vapor pathway from the subsurface to indoor air; the DNR may require a VMS when vapor concentrations beneath a slab, foundation or building exceed a VRSL (Wis. Admin. Code § 708.11(1)(b)). Submittal of a design plan overseen by a professional engineer for a VMS other than radon-type SSDS is required (Wis. Admin. Code §§ NR 708.11(4)(b), NR 724.02(1)(bm), NR 724.11 and NR 712.07(3)).

Regardless of the type[69] of VMS, the DNR recommends involving a mitigator experienced with chemical VI and certified by the National Radon Proficiency Program (NRPP) and using ANSI/AARST standards.[70] The NRPP trains service providers to meet basic best management practices for cost-effective mitigation. See Appendix F for recommendations on the design, commissioning, operation, maintenance, and decommissioning of a VMS.

[69] That is, a standard radon-type sub-slab depressurization system, a complex mitigation system, or a combination of mitigation options.
[70] https://standards.aarst.org

12 Stewardship of Mitigation Systems Prior To Case Closure

RPs and property owners must operate a VMS until no longer required by the DNR (Wis. Admin. Code § NR 724.13(1)(c)). Prior to case closure, property owners may be requested to allow the RP access to the property and system components and to notify the RP of system failure or damage[71] between routine inspections, if telemetry is not used (see Section F2.2.2). In most situations, the RP is responsible for performing OM&M of the system until case closure; however, the DNR may approve a proposed written alternative arrangement that is mutually agreeable to all stakeholders.

12.1 Assignment of Continuing Obligations at Approval of an Interim Action

The DNR may require the RP, through one or more VI COs (see Section 13.1), to maintain the VMS upon approving the interim action (Wis. Stat. § 292.12(2); Wis. Admin. Code §§ NR 724.13, 724.17). The DNR may assign other related COs to assure protection of public health and safety, including annual submittal of an inspection log (Wis. Stat. § 292.12(2); Wis. Admin. Code §§ NR 724.13, 724.17). The DNR is likely to assign the CO for annual submittal of an inspection log upon approval of the interim action when CVOCs are the contaminants of concern. The COs assigned at the time of interim action approval are typically similar to COs imposed at the time of case closure under Wis. Stat § 292.12(2) and Wis. Admin. Code chs. NR 726 and 727.

Example 1

TCE is a COC at an off-site single-family residence with a basement and an open sump where women who are or may become pregnant reside. The investigation identified either the potential for acute exposure or known acute exposure. For a proposed interim action consisting of a SSDS and sealed sump, the DNR may assign COs to the RP at the time of the interim action approval. Pursuant to Wis. Stat. § 292.12(2), Wis. Admin. Code §§ NR 724.13 and/or NR 724.17, the DNR may require the RP to:

a. Maintain the VMS, including the sealed sump and integrity of the foundation;
b. Maintain operation of the drain tile and sump system to allow performance of the VMS;
c. Conduct frequent or continuous monitoring of the VMS components. The DNR recommends active notification to achieve this;
d. Notify the DNR prior to building modifications; and
e. Routinely inspect and submit an inspection log (Form 4400-321) to the DNR at the required frequency.

Example 2

PCE is a COC at an off-site commercial property with a slab-on-grade foundation system. For a proposed SSDS, the DNR may assign COs to the RP at the time of the interim action approval. Pursuant to Wis. Stat. § 292.12(2), Wis. Admin. Code §§ NR 724.13 and/or NR 724.17, the DNR may require the RP to:

a. Maintain the VMS;
b. Conduct frequent or continuous monitoring of the VMS components. The DNR recommends active notification to achieve this;
c. Notify the DNR prior to building modifications; and
d. Routinely inspect and submit an inspection log to the DNR at the required frequency.

When CVOCs are present, the DNR is likely to require submittal of annual inspection logs (Wis. Admin. Code §§ 724.13(2)-(3)). The DNR recommends communicating this expectation with the off-site property owner and tenant(s) early during the mitigation process (Wis. Admin. Code § NR 725.05). The DNR recommends annual inspection of VMS by September 30 and submittal of inspection logs by October 15 when CVOCs are present.

[71] For example, audible alarm indicates SSDS fan is not operating, the manometer reading is substantially different than during commissioning, ice damaged the exhaust stack.

Anticipate these requirements when developing the OM&M Plan and consider discussing any questions with the DNR project manager. The DNR will detail any site-specific requirements in a letter at the time the COs are assigned.

The DNR will likely assign COs when approving interim action construction documentation, including the OM&M plan (Wis. Stat. § 292.12(2)). Interim action construction documentation must be submitted within 60 days of construction completion (Wis. Admin. Code § NR 724.15). The DNR considers the VMS construction to be complete after it is installed and fully commissioned[72]. Commissioning may take several months to a year or more after initial construction.

12.2 Mitigation Protection and Cost Efficiency

Investigating a building for VI, designing and installing a VMS, commissioning the system, and developing an OM&M Plan can take substantial time and resources. Chemical VI poses a chronic health risk to occupants and some sites pose an acute health risk, meaning that exposures as short as 24 hours may impact the health of the occupants[73]. Certain approaches allow optimization of the invested time and resources while assuring continued protection of human health, including:

- **Audible/visible alarm for activated systems.** An alarm allows the occupant to immediately notify persons responsible for OM&M of an electric or fan failure. This approach is included in ANSI/AARST standards as a best-management practice in the mitigation industry.
- **Telemetry system.** This enhances protectiveness by notifying necessary parties in the event of system disruption. Telemetry systems can reduce travel and entry to the affected building, and be used to remotely monitor basic items, such as the fan or electricity, as well as more detailed performance features such as pressure field extension (PFE) testing locations to verify continued capture beneath the footprint of a building. The DNR may assign site-specific COs other than the examples provided above when telemetry is utilized.

Without an active notification such as audible/visual alarm or telemetry, exposures may persist for weeks or months until the next routine OM&M inspection.

12.3 Potential Need to Recommission Prior to Case Closure

A VMS may need to operate for many years prior to case closure. Since the VMS serves to protect occupants from exposure to chemical vapors, recommissioning the system may be appropriate prior to closure. See Section F2.5.1 for situations where recommissioning prior to requesting closure is recommended.

12.4 Assignment of Responsibility for OM&M to Affected Property Owner

The responsibility for continued OM&M of the VMS typically transfers from the RP to the property owner (if they are different) at the time the DNR issues the case closure letter. The DNR recommends communicating with affected property owners regarding this transfer and the long-term plan, including when annual submittal of an inspection log is anticipated to be required. Transferring responsibility for OM&M from the RP to the property owner may warrant an update to the OM&M Plan and the addition of new contact information to the system labels. (Wis. Admin. Code § NR 724.13(4)). Prior to transfer, the DNR recommends the RP educate the property owners on the purpose of the VMS, how to maintain the system, and any submittals required as assigned by the COs (e.g., annual inspection logs). The RP must notify affected property owners in writing prior to submitting a request for case closure (Wis. Admin. Code § NR 725.05). A fillable notification letter, *Notification of Continuing Obligations and Residual Contamination* (Form 4400-286) is available to assist with this requirement. Visit dnr.wi.gov, search "4400-286."

[72] That is, the system is shown to be effective.
[73] DHS 2021 and DHS 2022. See Appendix H.

The RP and impacted property owners may negotiate an alternative arrangement (e.g., establishment of an escrow account for maintenance by the property owner, or RP maintenance of a telemetry system). The DNR recommends that any alternative arrangement between parties is clearly documented in writing and submitted to the DNR, although the DNR cannot enforce an agreement to which it is not a party.

The DNR may assign responsibility for a VMS to the property owner at approval of the interim or remedial action in some circumstances, such as when there is no viable RP (Wis. Stat. §§ 292.12(2), (5); Wis. Admin. Code § 724.13(1)(c)). The DNR will also document responsibility for OM&M in the closure letter.

Example - A municipality acquired a source property with naphthalene contamination and no viable causer was identified. The municipality qualifies for the local government unit exemption under Wis. Stat. § 292.11(9)(e). An off-site residence with a basement and sump has been impacted. Following approval of an interim action performed by the DNR through state-funded response action (for an SSDS with sealed sump), the DNR may assign COs to the affected off-site property owner. Under Wis. Stat. §§ 292.12(2), (5) and Wis. Admin. Code §§ NR 724.13 and/or NR 724.17, the DNR may require the property owner to:

a. Maintain the VMS, including the sealed sump and the integrity of the foundation;
b. Maintain operation of the drain tile and sump system to allow performance of the VMS;
c. Notify the DNR prior to building modifications; and
d. Routinely inspect at the required frequency and maintain the inspection log.

The DNR may impose other COs, depending on site specifics. (Wis. Stat. § 292.12(2)).

13 Continuing Obligations at Closure and Post Closure

13.1 Vapor Intrusion Continuing Obligations at Closure

Wis. Admin. Code § NR 726.15(2) lists several COs related to VI, summarized below:

DNR Case Closure Continuing Obligations: Vapor Intrusion (RR-042)
This guidance document is intended to help determine which VI CO to apply at the time of the case closure request. Visit dnr.wi.gov and search "RR-042."

- OM&M of a VMS due to VRSL exceedances (e.g., an SSDS is installed due to VRSL exceedances).
- COCs are in use (e.g., PCE is in use at an active dry cleaner).
- OM&M of a VMS due to hydrogeologic conditions (e.g., a SSDS with sealed sump is installed due to impacted sump and/or overlying a shallow groundwater plume).
- Site-specific exposure assumptions with limited occupancy/use (e.g., sub-slab vapor concentration exceeds residential VRSL at a commercial building but is below the small commercial VRSL and no mitigation is installed, residential use without mitigation is prohibited).
- Future VI risk (e.g., prohibit vapor migration into a new building, including building modifications or additions).
- Site-specific conditions (e.g., restrict occupancy at an unoccupied building unless mitigated).

13.2 Post-Closure Inspections and Audits for Vapor Intrusion Continuing Obligations

In addition to VMS maintenance, or occupancy limitations, the DNR may impose VI COs requiring routine inspections of the system or property and submission of the inspection log to the DNR (Wis. Admin. Code §§ 726.15(2)(h) and (m)).

When CVOCs are present, the DNR is likely to require submittal of annual inspection logs (Wis. Admin. Code § NR 727.05(1)(b)(3)). The DNR recommends annual inspection of VMS by September 30 and submittal of inspection logs by October 15 when CVOCs are present. The DNR will detail any site-specific requirements in a letter at the time the COs are assigned. See Section 10.7 for additional discussion about mitigation at new construction or building modifications after case closure.

The DNR may conduct periodic audits of these COs to ensure that potential exposure to residual contamination is addressed. The DNR provides notice before conducting site visits as part of an audit.

13.3 Post-Closure Modifications to Vapor Intrusion Continuing Obligations

Property owners must notify the DNR in advance of property or building modifications, including decommissioning, and may need to notify the DNR prior to changes in occupancy (Wis. Admin. Code §§ NR 727.07(4) and (5)).

RR-982 – Guidance on Post-Closure Modifications provides guidance on advanced notification requirements to the DNR for post-closure modifications. Visit dnr.wi.gov, search "RR-982."

A future vapor risk CO applies to the entire footprint of a tax parcel regardless of the location of residual contamination because preferential vapor pathways may be created during property development. Any proposed modifications to the property[74] have potential to impact the way vapors move from contaminated media into an occupied space. A future vapor risk CO requires the property owner to submit a post-closure modification request and associated fees to the DNR for review and approval, regardless of the proposed redevelopment (Wis. Stat. § 292.12(6); Wis. Admin. Code §§ NR 727.09, NR 727.11).

[74] For example, building modification, new construction, increased impermeable covers, installation of utilities.

13.4 Decommissioning After Closure

RPs and property owners are required to operate a VMS until the DNR no longer requires the system (Wis. Admin. Code § NR 724.13(1)(c)); decommissioning a VMS too early could cause adverse health impacts. VMS decommissioning after closure may be considered a post-closure modification (see Section 13.3). The DNR recommends a thorough evaluation of potential impacts and review of the OM&M Plan, which may include an exit strategy for the VMS. See Section F2.6 for technical recommendations on decommissioning.

Wisconsin DNR

Remediation and Redevelopment May 2025

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix A – Conceptual Model for Vapor Intrusion

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

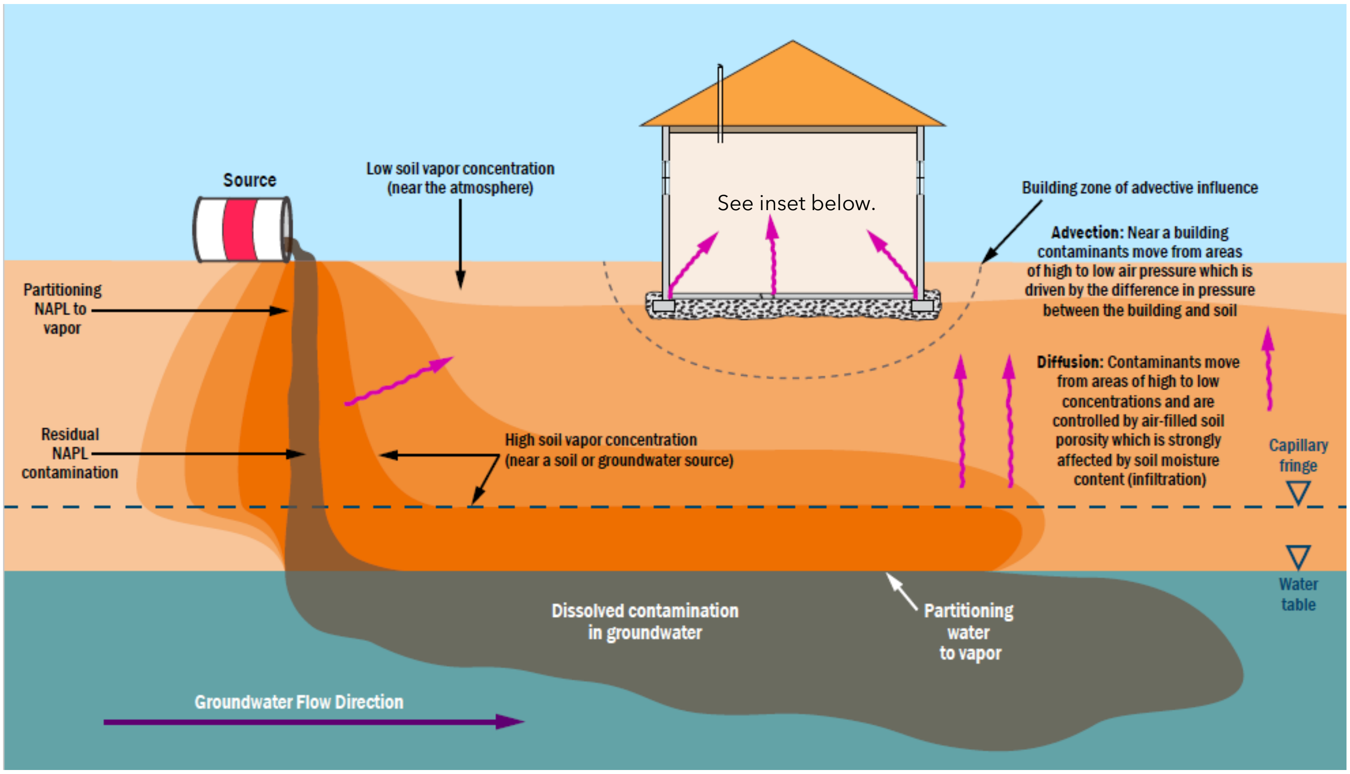
Contents

Figures

A1 General Conceptual Model for VI

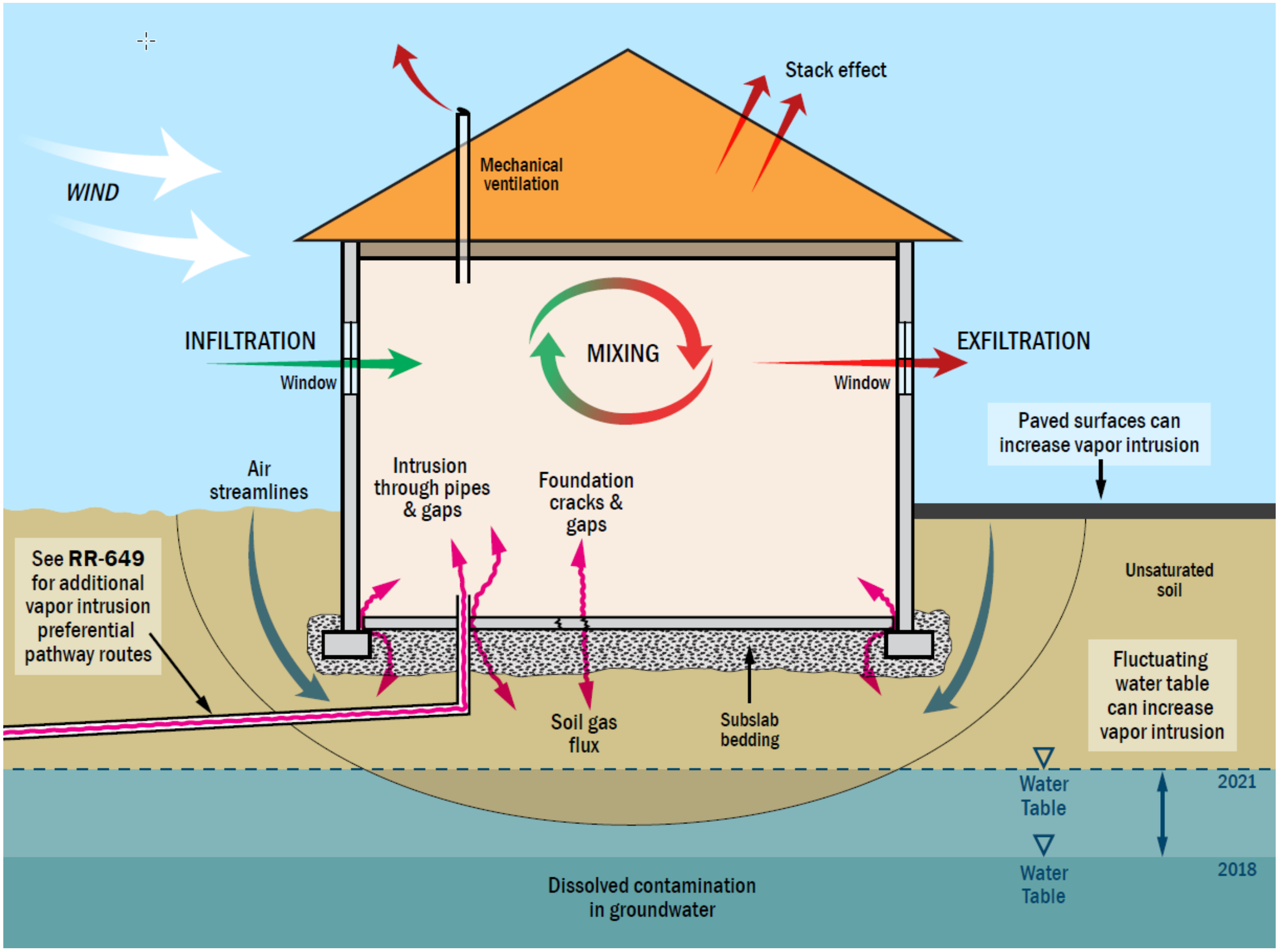
Volatile contaminants move primarily by diffusion from contaminated soil and groundwater outward and upward toward the land surface (Figure A-1). Vapors can migrate up to about 100 feet from contamination sources when the ground surface is not covered or permeable; however, under paved surfaces, contaminant vapors can accumulate and migrate farther[1]. When vapors are within 3 to 7 feet of a building [2], the negative interior pressure in most buildings draw the vapors in by advection through cracks in the foundation. Human-made preferential pathways and contaminated groundwater can allow contamination to migrate far from the source.

Figure A-1. Generalized Conceptual Model for VI - CVOCs



[1] Ibid.; Yao et al 2011.
[2] Although, effects have been reported up to about 16 feet. (Nazaroff 1987).

Inset for Figure A-1



A2 How Soil Gas Gets Indoors

Contaminated Vapor Accumulates Beneath the Foundation

Impervious building foundations slow contaminated soil gas from moving vertically to the atmosphere. Contaminant concentrations in sub-slab vapor continue to increase until the accumulation of contaminants is equal to the horizontal movement from under the slab to the atmosphere (see Figure A-2). When air pressure inside the building is higher than or equal to sub-slab conditions, little to no soil gas flows into the building through the foundation. This condition is likely during calm weather and with a slight difference between the indoor and outdoor temperatures.

Drop in Building Pressure

Lower outdoor temperatures compared to indoors can cause a stack effect, which lowers indoor air pressure relative to the subsurface. Wind load can also cause air pressure within a building to drop. The wind direction can also cause unequal air pressure distribution inside a building. Changing barometric pressure can also cause lower indoor air pressure compared to the subsurface.

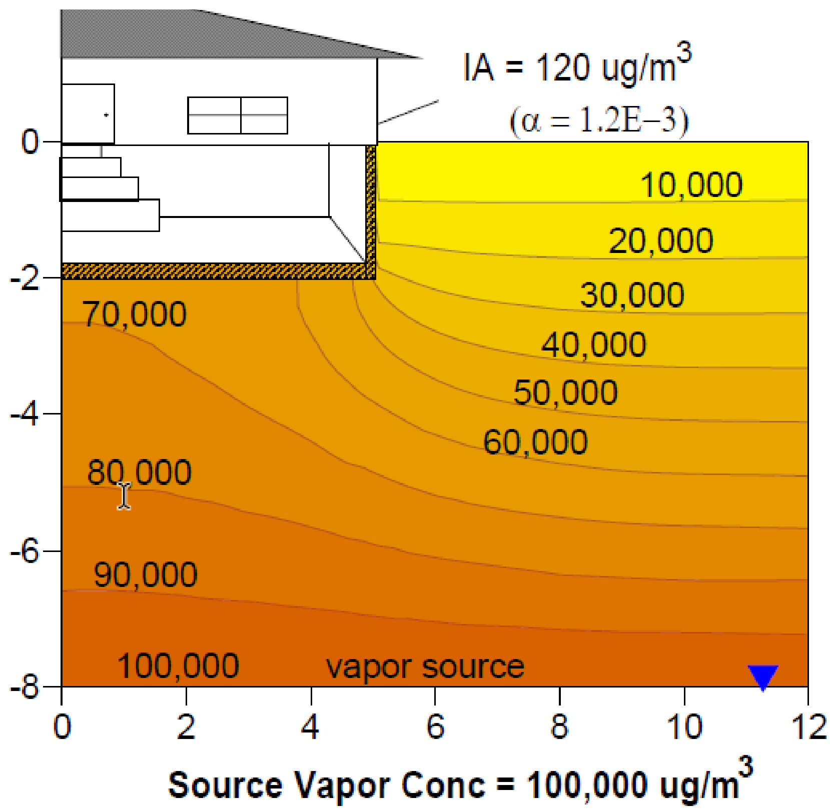
Mechanical ventilation and combustion appliances can cause negative interior air pressure; negative pressure from ventilation fans can be significant. Some building features such as elevators can also draw sub-slab vapor into the building due to negative pressures caused by their operation.

During cold weather, indoor air to subsurface pressure differences can be significant, especially when doors and windows are kept closed and makeup air cannot freely enter through open doors and windows.

Building features can affect indoor air pressure, such as:

Figure A-2. Vapor Concentrations Around a Building

X and Y scale are in meters. Alpha (α) is the source to indoor air AF. Source: U.S. EPA, *Conceptual Model Scenarios for the Vapor Intrusion Pathway*, EPA 530-R-10-003, February 2012.



- The location and size of cracks and spaces surrounding openings such as windows and the quality of windows themselves; the air pressure may vary throughout the building depending on the distribution of cracks, compromises and other openings.
- The presence of an air barrier that affects how sensitive interior pressure is to wind.
- Compartmentalized interior spaces that prevent air flow (e.g., air-tight doors between building levels).

Indoor Air Pressure Drop Draws in Contaminated Soil Gas

When pressure inside the building decreases relative to beneath the slab, contaminated soil gas that has accumulated in cracks and beneath the slab may be drawn into the building. The quantity, rate, and duration of the contaminant concentration change in indoor air depends on numerous factors:

- building features,
- texture of the surrounding soils,
- whether the surface surrounding the building is covered by an impermeable barrier (e.g., paved),
- rate of barometric pressure fluctuations, and
- the source and depth of contamination.

In poorly weatherized buildings, lower interior air pressure may draw in contaminated soil gas, but at the same time, outdoor air is also drawn in through leaks and cracks, resulting in contaminant concentrations that may not change much or may even decline.

A contaminant source close to the foundation, or a conduit pathway connected to the source (e.g., unsealed sump with contaminated water, open floor drain with a dried out p-trap), may cause contaminant concentrations in indoor air to stay at a higher level while the lower pressure condition is maintained.

As a result of this variability, two adjacent buildings that appear similar can be impacted by vapor intrusion (VI) quite differently.

Contaminant Concentrations in Indoor Air

The concentration of a contaminant in indoor air (C_i) is a function of the rate that contaminant enters the building through the foundation, the mass contaminant entry rate (Mer), the air exchange rate (AER) and the volume of the building (Vb). Mass contaminant entry rate (Mer) is equal to the product of the quantity of soil gas entering the building (Q_{soil}) and the concentration of the soil gas (C_{soil}) (See Figure A-3).

The AER is a function of how fast air enters and leaves the building. AER is controlled by unintentional infiltration and exfiltration of air through cracks and openings, as well as intentional ventilation such as the use of a kitchen or bath exhaust fan. The AER may vary daily as well as seasonally and may explain much of the variability of contaminant concentrations in indoor air samples. Temperature, wind, and barometric pressure impact both the AER and Mer.

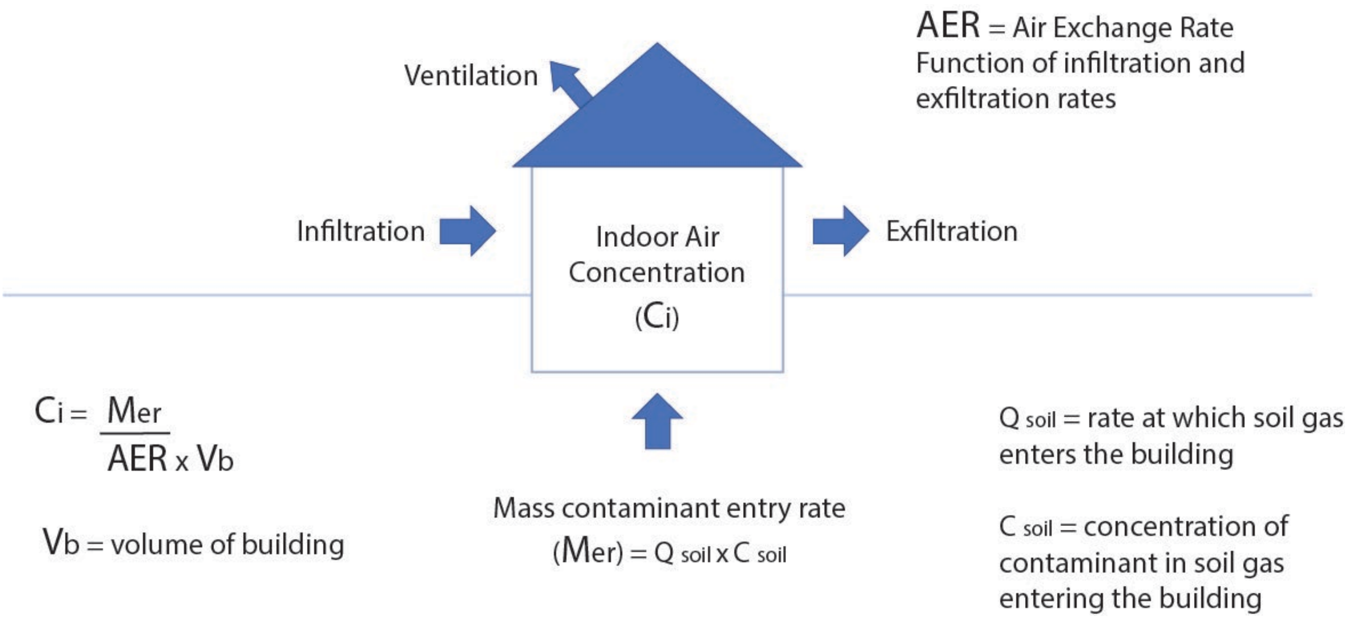
Any change that permanently affects the average AER of the building will impact indoor air concentrations. The most common change is weatherization to improve energy efficiency. When buildings are modified to increase energy efficiency, the buildings can become more susceptible to higher contaminant concentrations in indoor air.

Modeling studies and investigation of buildings where many samples were collected over time and space reveal that many factors affect indoor air concentrations, such as:

- variations in source concentrations,
- climatic factors,
- building features, and
- building operation.

Concentrations have been found to vary by one to three orders of magnitude (OM) within indoor air and from below detection on one day to many times the vapor action level (VAL) on the next.

Figure A-3. Contaminant Concentrations in Indoor Air



A3 Evaluation of Lines of Evidence

Contaminant vapors migrate from soil or groundwater sources through soil or conduits by diffusion and advection into buildings. Vapor concentrations differ over time and space (i.e., temporal and spatial variability) in soil gas, sub-slab vapor and indoor air due to many factors. One piece of information, such as indoor air concentration measured during a single day, may be insufficient to determine whether there is never an exposure to contaminant vapors or risk for VI. The DNR recommends incorporating multiple lines of evidence (LOE) and illustrating an understanding of the variables in the CSM for VI to support mitigation decisions. A LOE can be any piece of information that supports the accuracy of a conclusion if VI is occurring or has the potential to occur in the future. **However, some LOE are fundamental to every VI investigation**. These are listed below in order of typical relative importance. The weight of a LOE may be increased by collection of more data. See Figure A-4.

A3.1 Indoor Air Concentrations

Indoor air concentrations are the best indicator of whether VI is occurring and risk to health, incorporating all pathways into a building. Because assessing all pathways into a building is challenging, the DNR almost always recommends sampling indoor air when a building screens in (see Section 8.5.3) and giving indoor air concentrations the greatest weight as a LOE. However, indoor air concentrations can exhibit a high degree of temporal and spatial variability, particularly for large buildings, and reflect indoor or outdoor air sources unrelated to the release being investigated. Additional investigation may resolve inconsistencies between indoor air and other media (particularly sub-slab). Collecting supplementary information can assist in determining the source of contaminants found. These include:

- **Indoor sources**, such as in buildings with a history of solvent use, may warrant an evaluation of removable products and building materials. At a newly constructed building, trichloroethylene (TCE) entering through cracks and gaps in the foundation over a period of weeks to months may be sorbed by building materials, resulting in significantly degraded indoor air quality. Real-time sampling and measurement of isolated sections of building materials with passive samplers have been useful in evaluating off-gassing.
- **Indoor use of a contaminated water source**, such as water from a contaminated private well, indoors may cause an exceedance of a VAL. A contaminated indoor water source could present a VI risk equivalent to the risk from contaminated sub-slab vapor. Contaminants can enter indoor air during bathing and other water uses. If contaminated water continues to be brought into the house, evaluate the VI risk and conceptual site model (CSM) for VI. The Wisconsin Department of Health Services (DHS) may issue advisories for non-drinking water uses.
- **Tracer data**, including a natural tracer (e.g., radon) or an introduced tracer (e.g., perfluorocarbon), may be used to aid in determining whether contaminants are moving through the foundation or other barrier.
- **Outdoor air concentrations** may indicate whether outdoor air is a source of contaminants into indoor air from on-going emissions.
- **Sub-slab to indoor air pressure measurements** may indicate the likelihood of VI during the time of indoor air sampling. Days to weeks of monitoring may be warranted due to variability of air pressures in buildings.
- **Building information** such as foundation type and thickness, locations of footers, and the type of heating, ventilation, and air conditioning (HVAC) system may indicate whether the building design and operation would increase or reduce the likelihood of VI.
- **Meteorological conditions** such as temperature, wind speed and direction, and barometric pressure may significantly affect vapor concentrations during sampling. Data collected for these parameters can support the CSM for VI.
- **Conduit vapor concentrations** from plumbing cleanouts or sumps may indicate whether contaminants are or have the potential to enter indoor air.
- **Diffusion through a foundation:** High concentrations of sub-slab vapor can cause contaminant

vapors to diffuse through a competent foundation without significant cracking and could cause unacceptable indoor air quality, even after installing a sub-slab depressurization system (SSDS). Evaluate the contribution of diffusive transport during the design of a mitigation strategy when sub-slab vapor concentrations are in the hundreds of thousands to millions of μg/m^3.

A3.1.1 Indoor Air Sampling Strategies

Initial Sampling Event: The DNR recommends collecting initial samples quickly, regardless of season, to assess whether an acute exposure exists requiring immediate action. Initial sampling typically includes 8 or 24 hour evacuated canister or short-duration passive sampling. Real-time sampling may be a cost-effective alternative, or to supplement initial sampling, to quickly determine where concentrations are greater. Real-time sampling has been effectively used in large buildings and other complicated structures.

Collect Samples that reflect RME: Reasonable maximum exposure (RME) will most likely be observed during the winter months in Wisconsin. Highest indoor air concentrations are expected when temperatures are lowest and the stack effect is greatest. During this condition, doors and windows are closed limiting the AER. RME may be observed within a short time frame after an indoor air pressure drop (e.g., change in barometric pressure), or a change in wind velocity or direction. Cold air density is higher, increasing the impact of wind in winter.

Winter Assessment Period
This guidance uses the term *winter assessment period* for the period from December 1 through March 31. This timeframe is used to describe the sampling period for which RME is more likely to occur.

RME may occur during other times of the year. In situations with a shallow water table (typically within 5 feet of the foundation) changes in the water table elevation can increase VI, particularly if a rising water table contacts a building or groundwater enters an unsealed sump. In these cases, the DNR recommends proposing an alternative sampling approach that is justified by the CSM for VI. Time lags between a change in water table and maximum soil gas concentrations will depend on soil texture and are difficult to predict. Unless water is visible in a sump, selecting another sampling period during late spring through early autumn may be the simplest approach.

RME Sampling Strategies

- **Longer Duration Sampling Events:** When the initial sampling event does not definitively identify VI is occurring, performing supplemental sampling events over durations of 10 days or longer provide concentrations that better reflect long term exposure and minimize the risk of missing conditions that cause higher VI. Although the highest concentration for a single 8- or 24-hour period is not measured when a multi-day sample is collected, it is unlikely that a sufficient number of shorter 8-to-24-hour duration samples could be collected to determine this due to cost and access limitations. Passive sorbent samplers offer the most practical option for collecting longer duration samples. Although multi-day passive sampling events will not identify concentrations over each 8-to-24-hour period of the event, some samplers provide sufficiently low reporting limits to give assurance that the VAL was not exceeded at any time during the sampling event. As an example, if a 10-day sampler provided a TCE result of < 0.21 μg/m^3, the concentration over any single 24-hour period could not have been > 2.1 μg/m^3, the residential VAL. Even with longer duration sampling, more than one event will be needed during the winter assessment period (see Table 2 for recommendations).
- **Numerous Short Duration Sampling Events:** Historically indoor air samples were collected by evacuated canister over durations of 8 to 24 hours. Sampling at research buildings where hundreds to thousands of samples were collected in time and space indicates that tens of sampling rounds may be needed to adequately characterize vapor concentrations. Although

some buildings may exhibit less variability, this is difficult to predict without collecting many samples. For this reason, the DNR recommends performing longer duration sampling events to adequately evaluate risk for VI.

- **Create RME Conditions:** Manipulating indoor pressures may create conditions of RME similar to those produced by natural meteorological conditions. See Section 8.5.3. Building Pressure Cycling.

A3.1.2 Future Conditions

Evaluate whether future changes (e.g., climatic conditions, building modification, land use changes, occupancy changes) are likely to result in a VAL exceedance. See Section A4.10 for additional recommendations.

A3.2 Sub-slab Vapor

Samples from sub-slab vapor provide an important line of evidence (LOE) and are required when VI is a risk under Wis. Admin. Code § NR 716.11(3)(a). Sub-slab vapor samples may indicate whether contaminant vapors have migrated to the building foundation and trigger the need for mitigation. Sub-slab vapor concentrations can vary due to:

- unknown soil conditions beneath a foundation,
- soil source concentrations,
- building construction, and
- sub-grade preferential pathways.

The DNR recommends considering the building size and complexity when determining the number of data points to characterize sub-slab vapor concentrations for the building footprint. Installing sub-slab vapor ports near the center of the foundation slab in a smaller structure, away from the edge of the building, reduces the likelihood of effect from outdoor air intrusion due to wind or changes in barometric pressure.

Concentrations may vary significantly at buildings overlying a shallow groundwater plume when there are changes in the water table elevation. The importance of sub-slab vapor results as a primary LOE can be increased by sampling more locations and performing additional rounds. However, building conditions and occupant preferences often impose limitations to locating sub-slab vapor ports in ideal sampling locations due to business operations, placement of personal belongings, expensive floor coverings (e.g., tile), foundation elements, etc.

Collecting longer duration samples may improve characterization. Collecting some higher volume samples in large buildings can improve characterization (see section 8.5.2, High Purge Volume Sampling).

A3.3 Groundwater and Soil

Soil and groundwater sampling is conducted to comply with the requirement of Wis. Admin. Code § NR 716.11(5)(e) and (f). Results from this sampling typically determines if a VI investigation is also needed.

Soil: Accurately assessing the degree and extent of concentrations in soil is difficult due to the limited aerial extent of each sample (typically a few square inches) compared to the large areas that require assessment (often hundreds to thousands of square feet). Even a small area of contaminated soil can be a significant source of contaminated vapor and may be difficult to locate, particularly beneath a large building foundation. In addition, historical use information may be limited. Conversely, contaminated soil gas results may indicate areas of soil contamination, particularly when collected beneath a foundation or other impermeable surfaces. Significant VI has been identified at sites where initial soil sampling did not predict a risk and discrete contaminated soil source areas were difficult to locate.

Groundwater: Groundwater concentrations tend to vary less than vapor concentrations and fewer sampling locations are typically needed to characterize concentrations. Some conditions may limit vapor movement from a groundwater source (e.g., soil permeability); some of these factors may be short-lived (e.g., wet soil).

A3.4 Soil Gas

Collecting soil gas samples may help when evaluating whether contaminant vapors have migrated from groundwater and soil sources. Rigorous quality assurance/quality control (QA/QC) procedures are needed to obtain an accurate soil gas sample. Soil conditions that affect contaminant concentrations can vary considerably over time and space. Sub-slab vapor concentrations having been found 2 to 3 OM greater than nearby soil gas concentrations. Collecting soil gas samples often confirm a nearby building should be sampled for VI. Passive soil gas probes installed at a shallow depth can be used in this regard, although soil gas sampling adjacent to a soil or groundwater source provides another LOE about potential VI risk. Developing a convincing LOE to rule out VI often necessitates multiple sampling rounds, collected at soil gas probes installed at various depths (i.e., horizontal and vertical profiling). Consider the following factors when conducting soil gas sampling:

Capillary Fringe Thickness and Stability: The capillary fringe is the layer of saturated soil immediately above the water table, where water is pulled up by the capillary forces within the soil. The height of the capillary fringe is influenced by soil texture and ranges from less than a foot in sandy soils to several feet in finer textured soils. Most pore spaces in the capillary fringe are filled with water, which slows diffusion of contaminated vapor from the surface of the water table. Contaminant concentrations in vapor equilibrate to concentrations in groundwater over time. Concentrations in soil gas over a shallow water table with relatively dry soil may reach a near-steady state at the foundation within weeks or months; however, concentrations over deeper water tables with wetter soil, or a greater lateral distance from the source, may take years to reach a near-steady state at a foundation. Reaching a near-steady state also takes longer under an impervious upper boundary (e.g., surface paving.)

Fluctuating Water Table: A water table that fluctuates can dramatically affect VI. A stable water table elevation allows the soil in the capillary fringe to provide resistance to upward-moving contaminated vapor. Soil gas concentrations above a fluctuating water table may increase due to several variables:

- A rising water table beneath a building shortens the distance to the contamination source.
- High contaminant concentrations in soil gas can occur as a water table falls. Mass flux of contaminants from soils increases due to contaminants being introduced to lower moisture content conditions in the vadose zone.[3] This effect is most significant in examples with a shallow water table and gas conductive soils.
- A changing water table can induce advective movement, which may increase the risk of VI.[4]
- Vapor concentrations at sites with coarser grained soils may be more sensitive to groundwater fluctuations.[5] Bubble-facilitated transport, where mass transfer from non-aqueous phase liquid (NAPL) to entrapped air gas bubbles occurs during water table fluctuations. The expansion and vertical migration of the bubbles may result in higher mass contaminant flux into buildings.[6]

Soil Moisture Content: Diffusive flow is a function of the concentration gradient and the portion of soil pore space filled with air, and the degree to which air-filled pores are interconnected. The portion of soil pore space filled with air decreases when the moisture content of soil increases. Moisture content is an important control of diffusion because contaminant vapors diffuse through air about four OM (10,000 times) faster than water.

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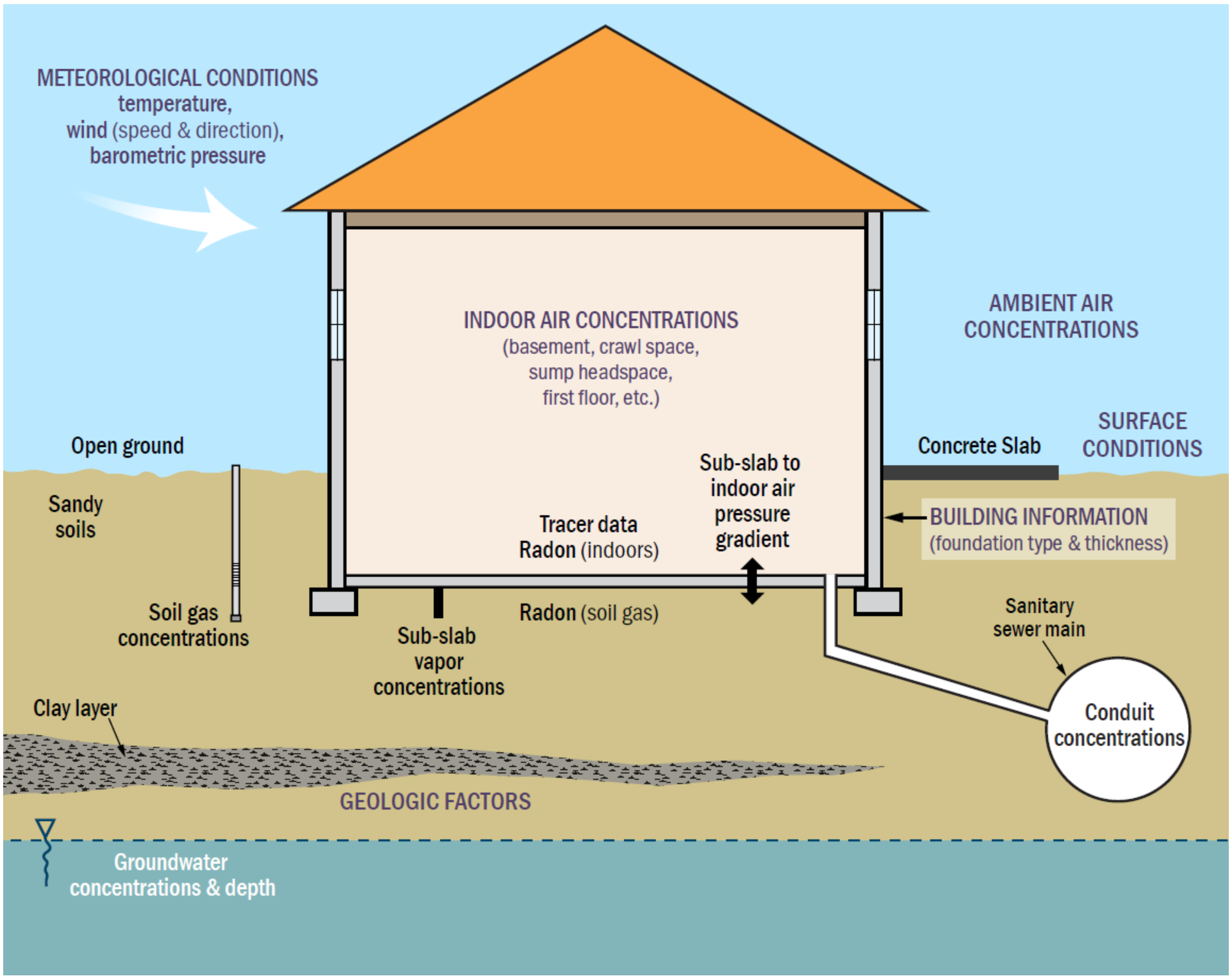
[3] Liu et al 2021.
[4] Man et al 2021.
[5] In this simulation, indoor air concentrations increased by about three times due to a water table oscillation of 1.31 ft. over four days.
[6] Werner and Höhener 2002 and Ma et al 2019.

Precipitation events, seasonal wet conditions, an intermittent perched water layer, and the capillary fringe can affect soil moisture content and vapor diffusion.

Surface conditions: Soil gas concentrations within about 5 feet of the land surface can be strongly impacted by changes in barometric pressure and diluted by outdoor air when the land surface is cover by open ground (bare or vegetated soil). Under impermeable cover (asphalt, concrete and buildings), soil gas does not readily exchange with atmospheric air and concentrations may increase.

Figure A-4. Common LOE and/or Variables for Vapor Investigation



A4 Elements of a CSM for VI

The CSM for VI for a VI field investigation incorporates elements that may affect vapor movement. See Figure A-4 for an example of a CSM for VI that includes those elements. The information in this section includes elements to consider in a CSM for VI.

A4.1 Boundary Delineation

The initial boundary of the CSM should be based on a known location of contaminant sources, available soil gas data, knowledge of pathways, and location of receptors using screening criteria provided in Sections 2.4 and 2.5. The CSM boundary should be adjusted as the investigation proceeds and new information is obtained.

A4.2 Contaminant Identification and Characteristics

Chlorinated volatile organic compounds (CVOCs) pose a VI risk at most sites. Some CVOCs (e.g., vinyl chloride) are known to degrade in the vadose zone, but most do not. Use the screening guidelines in Section 2.4 when CVOCs are present.

Petroleum volatile organic compounds (PVOCs) readily biodegrade in the presence of oxygen and adequate numbers of micro-organisms. Use the screening guidelines for PVOCs in Section 2.5 when PVOCs are present.

Petroleum Additives: Some petroleum fuels contain additives with rates of degradation different from PVOCs. PVOC screening guidelines may be inappropriate. Common additives include ethylene dibromide (EDB), 1,2-dichloroethane (1,2-DCA) and methyl tert-butyl ether (MTBE). The presence of other compounds such as ethanol may impact PVOC biodegradation and pose an additional risk of methane generation, creating explosive conditions. The DNR recommends completing screening assessments on a case-by-case basis for these compounds; see Section 2.5.3 for more information.

Methane: Waste materials, sewers, naturally occurring organic material (e.g., peat), and biodegradation of contaminants can generate methane and pose a VI risk and explosive conditions. See DNR guidance documents *Development at Historic Fill Sites and Licensed Landfills: What you need to Know* (RR-683), *Development at Historic Fill Sites and Licensed Landfills: Guidance for Investigation* (RR-684), and *Development at Historic Fill Sites and Licensed Landfills: Considerations and Potential Problems* (RR-685) for screening, investigation, and mitigation recommendations for methane.

VOCs, SVOCs and other contaminants can cause VI risks. If VI from other compounds is suspected, the DNR recommends discussing the screening and investigation methods with the DNR project manager. The U.S. EPA Vapor Intrusion Screening Level (VISL) Calculator may be used as a starting point to determine if the compound is sufficiently toxic and volatile.

Related chemicals: The existence of one compound may indicate the presence of other related compounds. A common example is PCE and its breakdown product, TCE. If PCE is present, the DNR recommends also analyzing vapor samples for TCE; the presence of TCE may present a higher health risk due to its inhalation toxicity and developmental endpoint. See Section 8.2.1 Analyte List for more information.

A4.3 Sources of Contamination

Release Activities: Site scoping must include an evaluation of the activity that likely caused the discharge of hazardous substances posing a VI risk (Wis. Admin. Code §§ NR 716.07(1) to (3)). Include an evaluation of all pertinent records and building surveys. Certain commercial and industrial processes may present higher risk from VI (i.e., dry cleaning and metal degreasing). Understanding how the businesses handled solvents is key for developing a CSM for VI. See Appendix C for more information.

Background Sources: The DNR recommends identifying background sources of the contaminants of concern (COCs) that could exist within the boundary of the VI CSM. These could occur in the surface, subsurface, indoor air, outdoor air, and conduits. An initial evaluation of all pertinent records and building surveys may provide useful information.

Soil: Select sample locations for soil using historical information about the delivery, storage, use, and disposal of chemicals (Wis. Admin. Code §§ NR 716.07(1)-(4), NR 716.11(3)(a), (5)(a), (e)).

Groundwater: Consider the following factors when collecting groundwater samples to evaluate the vapor pathway (Wis. Admin. Code §§ NR 716.07(4), NR 716.11(5)(e)-(f)):

- **Contaminant Concentrations:** Use sampling methods that accurately measure concentrations at the water table surface. Concentrations can vary and the number of wells that can be installed is limited; therefore, use the maximum groundwater concentrations at the water table for screening. Evaluate concentrations at both the water table and the perched groundwater layer where applicable. When the water table is close to the surface, the concentrations at the water table surface may be lower beneath open ground than beneath adjacent structures. Contaminants under open ground diffuse upward and eventually escape to the atmosphere. Diffusion in water is about four OM lower than air; therefore, the rate of contaminant movement from deep groundwater to the water table surface may be significantly less than the loss of contaminants from a shallow water table surface into the vadose zone, possibly causing a decrease in concentration at the water table surface.
- **Plume Margins:** Accurately identify the margins of the groundwater plume with contaminant concentrations relevant for screening in relation to existing buildings and determine where a VI risk to future buildings may occur (see Figures 2 and 3).
- **Depth to Water Table:** Contaminant concentrations in vapor near the surface decrease linearly as the depth of the groundwater contamination source increases in homogenous soil conditions. Contaminated vapor has less distance to attenuate over a shallow water table. Contaminated groundwater entering a building through a sump (or similar opening) can allow dissolved contaminants in groundwater to volatilize directly into indoor air.
- **Clean Water Lens:** CVOC plumes may dive beneath the water table surface due to downward hydraulic gradient and contaminant density, resulting in groundwater at the water table surface that is not contaminated a short lateral distance from the source. Because it can reduce VI risk, the U.S. EPA recommends a groundwater AF of 0.0005 when a laterally extensive fine-grained layer with a high moisture content is present in the vadose zone. Contaminant concentrations in groundwater in discharge zones can greatly vary over space and time. The upward movement of contamination in a down-gradient discharge zone can result in VI into buildings. When a clean water lens is present, collect enough LOE and assess the stability of the groundwater plume to justify screening out an overlying building (Wis. Admin. Code § NR 716.11(3)(a)).

NAPL: If NAPL reaches the capillary fringe, water table fluctuations can smear the product vertically and enhance the vertical mixing of vapor and dissolved contamination, which may result in higher sub-slab vapor concentrations and more variability over time.

A4.4 Pathways – Geologic Factors

Soil gas conductivity is a measure of how easily a volume of soil gas moves through the soil (compared to diffusion, where only the contaminant moves). Soil gas conductivity and the pressure gradient control advective gas flow. Soil gas conductivity is primarily a function of pore size, which depends on the texture of the media (much higher in sands and gravels than clay), pore interconnectedness, and features such as fractures and roots. Generally, advective flow is important only near the land surface due to atmospheric pressure changes, if a vacuum is applied (e.g., evacuated canister sampling), or near buildings due differential pressure across the foundation. In these situations, the DNR recommends that site investigations include an evaluation of the effect of soil texture of sub-foundation bedding on soil gas movement.

Soil moisture content in vadose zone: Diffusion is strongly controlled by air filled porosity. Measuring soil moisture content is an important component if soil gas concentration measurements are being used to support the conclusion that the VI risk is low.

Natural preferential pathways (fractured bedrock & clay, karst): Natural features can provide direct routes of contaminant migration. Areas of fractured bedrock or clay and karst that are open to the atmosphere can be vapor conduits for advective flow or change the direction of flow due to seasonal changes or barometric pressure changes. The CSM for VI for the vapor intrusion field investigation should reflect natural and human-made preferential pathways.

Flooding: Surface flooding may transport contaminants and may need to be considered in areas subject to periodic flooding. Flooding that occurs after an investigation is complete can cause contamination distribution to change; the buildings and CSM for VI may need to be re-evaluated.

A4.5 Soil Gas Contaminant Concentrations

Soil gas samples taken close to the ground surface are likely to be affected by atmospheric conditions. The DNR does not recommend using data from the top five feet of an open ground surface to make risk decisions. When evaluating a source of contamination in groundwater, source contaminant concentrations in soil gas samples collected just above the capillary fringe tend to be less variable than samples collected closer to the ground surface. However, concentrations may vary due to changes in source and water table elevation. Soil gas samples collected within the capillary fringe are unlikely to provide representative information due to the high moisture content. Given the potential variability, the DNR recommends that soil gas samples collected outside the foundation of a building should only be used as a strong LOE that there is not a VI risk to a building through collection of a sufficiently large number of samples at multiple depths (i.e., vertical profiling) and events using rigorous sampling procedures.

A4.6 Pathways - Human-made Sewers, Surface and Subsurface Drainage

Human-made preferential pathways can transport contaminants far from the source. Conduits such as sanitary sewers provide a pathway with little resistance to vapor movement between the source and indoor air. A CSM for VI that relies on screening setbacks (i.e., exclusion zones) based on either diffusion-based models or observations may not be valid when preferential pathways exist. The DNR recommends conducting vapor sampling within the conduit and indoor air to evaluate the VI risk. Indoor air samples reveal if VI is occurring at the time of the investigation. Conduit samples reveal whether there is a potential future risk. See *Guidance for Documenting the Investigation of Human-made Preferential Pathways including Utility Corridors* (RR-649) and Section 8.3.3 for sampling recommendations for human-made preferential pathways.

A4.7 Receptors

Occupied buildings (including infrequent occupancy)

- **Building Use:** Indoor air sampling needs are based on the building use and whether the COCs are used in the building. Building use also determines which VALs and vapor risk screening levels (VRSLs) apply (see Section 9). A building survey may be used to capture this information.
- **Occupant Demographics:** Occupant demographics influence the timeframe for response actions. Determine if women who are or may become pregnant, children or other sensitive occupants are present. If TCE is present at or above its VAL and women who are or may become pregnant are present, immediate actions may be needed. (Wis. Admin. Code § NR 708.05) See Figure 2, Table 2 and Section 3 for additional information.
- **Occupant Disruption:** A VI field investigation may disrupt the lives and livelihood of people who own, live and work in the subject buildings. Performing numerous sampling events can increase disruptions. The DNR recommends balancing sampling needs with owner and occupant concerns when creating a sampling strategy and making risk decisions. Longer duration samples collect more data during fewer

entries and may minimize disruptions. The DNR and DHS and/or local health agencies can help in attempting to gain access and communicate risk (see Section 4).

Properties/Areas that could be developed (including unoccupied buildings)

- **Future Development:** A VI field investigation identifies undeveloped areas of properties where construction of a future building may result in a VI risk to future occupants. Make an evaluation based primarily on screening guidelines for soil and groundwater concentrations (Figures 2 and 3). The proximity of an undeveloped parcel to a utility conduit with contaminated vapor may also be a future VI risk. Soil gas samples collected on an undeveloped property cannot predict vapor concentrations under a future building because contaminant concentrations in soil gas are influenced by the placement of an impervious surface and the operation of building HVAC systems.

  The DNR uses the screening criteria in Figures 2 and 3 when evaluating if a continuing obligation (CO) is needed to address future vapor risk at case closure or approval of an interim or remedial action. When this CO is imposed, vapor control technologies may be required for future occupied buildings, unless a VI field investigation is completed following construction and the DNR agrees that vapor control technologies are not needed (Wis. Stat. § 292.12(2), Wis. Admin. Code § NR 726.15(2)(L) and (m)) (see Sections 10.6 and 10.7 for recommendations on evaluating new construction and Appendix F for recommendations on mitigation for new development).

- **Development Plans:** The CSM for VI should include a review of local zoning and development plans for the area. During long term investigations, the DNR recommends the responsible party (RP) stay up to date on development plans and inform developers and municipalities about any potential contamination impacts due to proposed development plans.

A4.8 Buildings/Infrastructure

Sub-grade Material: The nature of the soil or fill material beneath the slab affects movement of vapors between the building, native soil, atmosphere, as well as vapor contaminant concentrations in both soil and indoor air. A granular fill layer is present beneath some building foundations for support and drainage; however, older buildings in areas with predominantly clay soils may not. Predominantly clay and fine-grained soils can inhibit vapor movement and pose challenges for assessment and mitigation. The foundation slab acts as an additional impediment to investigation, making it difficult to adequately characterize sub-grade materials. Higher indoor air concentrations may be present in commercial buildings with fine-grained soil compared to buildings with coarse-grained soil or a base course as fine-grained soils retain contaminants to a greater extent.

Foundation Slab: A building foundation slab provides the primary barrier to sub-slab vapors entering indoor air. Thicker foundation slabs found in large commercial and industrial buildings are generally more protective; however, diffusion through concrete can be the primary source of VI at sites with high sub-slab vapor concentrations.

Most buildings with a foundation slab have a perimeter crack where the slab meets the perimeter foundation wall. Default AFs assume buildings have a poured concrete slab and some susceptibility to VI due to a perimeter crack; however, default AFs are not appropriate if the building has a dirt floor, unlined crawl space, open sump, atypical foundation joints, large cracks or deteriorated concrete. As concrete dries out, its gas conductivity may increase, which also increases the potential for greater vapor flux. Some recently constructed buildings may incorporate radon resistant foundation elements (e.g., soil gas barriers, venting layers), which may limit VI, but are not a substitute for a VI field investigation and possibly additional mitigation actions. The depth of the foundation also impacts the likelihood of VI. Typically, buildings with basements are more susceptible to VI than slab-on-grade structures in similar settings. Interior footings or changes in foundation type across a building may affect vapor movement and concentrations. Sampling schemes must account for this factor.

Foundation Walls: The condition and composition of foundation walls is an important component of VI field investigations. Foundation walls with cracks or constructed of field stone or hollow blocks can allow contaminated vapor to bypass the basement or lower levels and move vertically within the building; indoor air samples from the lowest level may not reflect the highest concentrations within the building. Contaminated vapor may also enter through cracked exterior walls adjacent to a soil contamination source.

Points of Vapor Entry: The default AF accounts for typical foundation penetrations such as water service and sewage utilities. Use of default AF may not be appropriate for buildings with other penetrations that create more significant points of entry, like unsealed sump pits, especially where a soil or groundwater source is close to the foundation.

The risk of VI increases from unsealed sump pits if the sump or drain tile lines contain contaminated water. High contaminant concentrations in vapor have also been found in the headspace of dry sumps. Samples from sump liquid in addition to headspace vapor is useful for finding points of contaminated vapor entry. Section 8.5.2. provides recommendations for assessing unsealed sumps.

Building Layout and Size: Features that restrict air movement within zones of a building can create areas of higher contaminant concentrations in indoor air. Features that may restrict air movement include partitions, walls, floors and ceiling height. Taller buildings, stairwells, and elevators may enhance VI by creating lower pressure zones due to temperature differentials. Large buildings can have different contaminant concentrations near the center of the foundation because contaminated sub-slab vapor is susceptible to atmospheric effects near perimeter walls. If soil oxygen content is much lower near the center of the building foundation, assumptions about biodegradation may need review. More complex buildings require more samples for characterization.

Envelope: The number and location of openings in the exterior walls (e.g., windows, doors, electrical outlets) affect air movement in the building, particularly when coupled with the effect of wind.

Buildings with poorly sealed doors and windows are more likely to have AER and indoor air vapor concentrations impacted by wind and temperature.

Temporary or permanent efforts to weatherize a building will also affect air movement and indoor air contaminant concentrations; this is most frequently seen in building weatherization to reduce energy consumption.

Pressure Gradient: The pressure gradient between the sub-slab and interior of a building primarily determines if air moves from the subsurface into indoor air. The direction and magnitude of the pressure gradient are influenced by operation of HVAC systems, temperature differences from inside to outside air, barometric pressure, wind speed and wind direction. Lower floors of a building may have interior pressures that are negative in relation to sub-slab and outside air. Many commercial and industrial buildings are operated to maintain a slight positive interior pressure and may be less susceptible to VI; however, zones of negative pressure may exist that result in VI. Barometric pressure changes can cause rapid interior pressure fluctuations in buildings that were designed to maintain positive pressure, resulting in greater contaminant concentrations in indoor air than when the building operates under continuous negative pressure. A micromanometer can be used to measure sub-slab to interior pressure. Data loggers that collect pressure differential over long periods of time can help determine whether vapor sampling was performed over a time period when VI was more likely to occur.

Occupant Behavior: Contaminant concentrations in indoor air and pressure differentials can be affected by building occupants who use doors, windows, HVAC and mechanical ventilation (e.g., kitchen and bath fans) during sampling. Appendix B provides instructions for occupants to help balance the effects of occupancy on sampling with the level of disruption to building occupants.

Land Surface Effects: The land surface feature around a building can affect contaminant concentrations in sub-slab vapor. For example, a building surrounded by a paved surface with positive, oscillating indoor air pressure can have significantly higher contaminant concentrations in indoor air than the same building with constant negative pressure and surrounded by uncovered ground surfaces. Paving the land surface around a building can increase the VI risk. Low permeability ground cover may also increase concentrations of contaminants in shallow soil vapor.

A4.9 Meteorological Factors

Temperature: VI tends to be highest during winter months when buildings are heated and during periods of fluctuating weather conditions. Heated air inside a building rises and exits the building through cracks and openings higher in the building. This dynamic can create negative pressure in the lower parts of a building, drawing in outside air through windows or cracks in lower outside walls of the foundation. Higher VI may occur in summer months in some buildings due to use and HVAC operation. Measuring pressure differentials can verify dynamics related to temperature in the building.

Barometric Pressure: Barometric pressure can fluctuate significantly daily within a building. VI typically increases when barometric pressure decreases.

Wind: Average wind speed and prevailing wind direction vary by location and season. In Wisconsin, lower wind speeds tend to occur in summer and higher wind speeds from winter to early spring. Wind can create high pressure on the windward side of the building, forcing atmospheric air into the sub-surface, and diluting sub-slab vapor concentrations on that side of the building. Wind can also create high- and low-pressure zones within a building and significantly affect AERs and contaminant concentrations. If a building has more openings on one side, wind direction can cause contaminant concentrations in indoor air to vary significantly. Leakier buildings are more likely to have interior pressures and contaminant concentrations impacted by wind.

Precipitation: Higher soil moisture content around a building can inhibit venting of contaminants to the atmosphere and cause contaminant concentrations in vapor to increase beneath the building.

A4.10 Future Conditions

Future Groundwater Conditions: The DNR cannot close a case if remaining levels of contamination are likely to pose a threat to public health or cause a VAL to be attained or exceeded. (Wis. Admin. Code §§ NR 726.05(4)(a) and (e) and NR 726.05(6)(d)). The DNR recommends meeting public health protection criteria by making conservative mitigation decisions rather than predicting future vapor concentrations through modelling. If contaminant concentrations in indoor air or sub-slab vapor are below but near action concentrations, consider the likelihood that contaminant concentrations in vapor may increase when making mitigation decisions. Multiple LOE should be considered. The DNR recommends collecting information on both the direction and magnitude of water table variation, areas of a water table that are trending upward or downward in the long term, and buildings with foundations that can be intersected by a rising water table. The shallower the water table, the more important it is to evaluate.

Future Building Conditions: Future conditions affecting VI can include weather, building structure and operation, ground cover around the building, and variations in the water table. A detailed building evaluation that includes a determination of AER during sampling, building pressure cycling (BPC) test, and a statistical evaluation of building vapor data and factors which affect vapor concentrations (e.g., indoor/outdoor temperature differential) can help evaluate whether future meteorological factors or changes in building operations may lead to higher vapor concentrations. Even a simpler evaluation of site features may indicate whether vapor concentrations in the building may be higher in the future. It is important to note that foundation cracking tends to increase as a building ages.

Certain aspects, such as variations in the elevation of the water table or effect of paving the area around the building, are difficult to predict, even with a sophisticated model. Although contaminant concentrations are expected to decline over time, the decline for CVOCs can take many decades. If these site features are present, mitigation may be warranted if other LOEs point to the likelihood of a vapor risk.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix B – Instructions for Occupants

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

The items in the list below can be tailored for the COC, the duration of sampling, and for a commercial or industrial property. Some activities are less likely to impact measurement of certain COCs (e.g., smoking or parking in an attached garage during measurement of TCE concentrations). Occupants would likely find some recommendations unreasonable over longer durations.

The DNR recommends providing the following communication and instructions to occupants of buildings that will be sampled.

Your cooperation is greatly appreciated. If you have any questions, please feel welcome to contact ______________ at _________________.

Sampling date: ________

Prior to sampling, we will ask questions about your building: the structure, consumer products you store and use, and activities that occur. Your answers help us:

1. Identify locations where contaminants could be entering your building, for example, through foundation cracks or plumbing fixtures, so that we can collect samples in the best locations,
2. Identify activities or building features that can affect sample results, such as bath fans and heating and cooling systems, and
3. Identify if there are sources inside your building of the chemicals we are analyzing.

About two days before the sampling date, please remove any household products and materials that could contribute volatile organic chemicals to the indoor air. This is because many consumer products contain the same chemicals that we are investigating.

At least one day prior to and during the sampling event, we ask you to do the following:

- **Do** operate your furnace and whole house air conditioner as appropriate for the current weather conditions
- **Do** operate ventilation fans as normal
- **Do** continue normal entry and exit
- **Do not** open windows, fireplace openings or vents
- **Do not** keep doors open except for normal entry and exit
- **Do not** use air fresheners, scented candles, or odor eliminators
- **Do not** smoke in the building
- **Do not** use wood stoves, fireplace, or auxiliary heating equipment (e.g., kerosene heater)
- **Do not** use paints or varnishes
- **Do not** use cleaning products (for example, bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners)

- **Do not** partake in indoor hobbies that use solvents (for example, gun cleaning, model painting)
- **Do not** apply pesticides
- **Do not** bring dry-cleaned clothing into the house
- **Do not** store containers of gasoline, oil, or petroleum–based or other solvents within the house or attached garage (except for fuel oil tanks)
- **Do not** operate or store automobiles in an attached garage
- **Do not** operate gasoline powered equipment within the building, attached garage or around the immediate perimeter of the building
- **Do not** use other common household sources of indoor air contamination, listed on the attached table

Attach Table 4, Common Household Sources of Background Indoor Air Contamination Listed by Product.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix C – Common Commerical and Industrial Sources of Vapor Intrusion

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

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This document is intended solely as guidance and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

C1 History of Dry Cleaning Operations

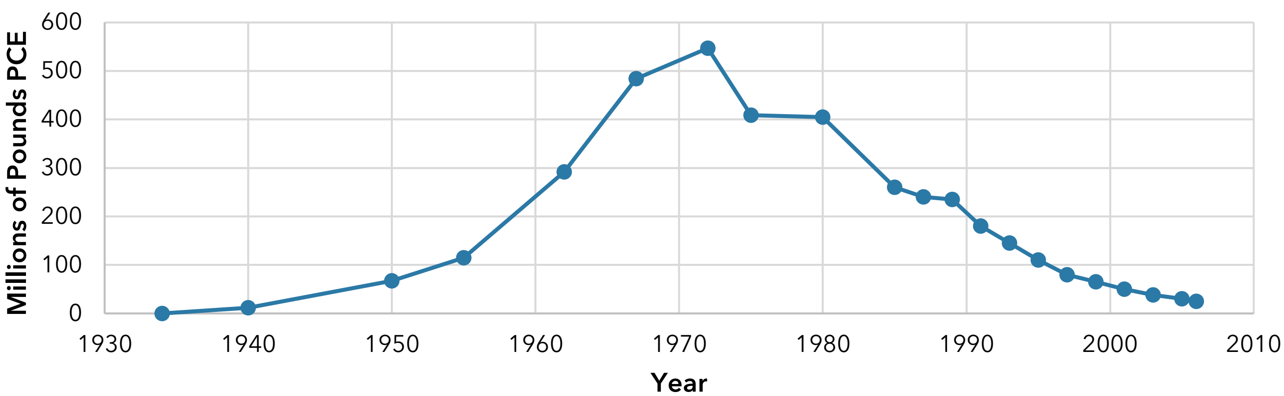
C1.1 Solvent Use

Over the years, different chemicals have been used for dry cleaning. Prior to the 1940s, most dry cleaners used petroleum-based compounds such as gasoline or Stoddard solvent,[1] or chlorinated compounds such as carbon tetrachloride (CT) and trichloroethylene (TCE). Stoddard solvent was the predominant dry cleaning solvent from the early 1940s until the late 1950s. (Morrison 2013). Perchloroethylene (aka Perc, tetrachloroethylene, or PCE) was first used in 1934 and increasingly replaced most other compounds. By 1954, 33% of all dry cleaners used PCE, exceeding 50% by 1959 (Morrison 2013).

Photo 1. Container of TCE

By 1962, 90% of PCE consumption in the U.S. was by dry cleaners.[2] The amount of PCE used by dry cleaners peaked in the early 1970s (see Figure C-1). Its use declined due to the increased efficiency of dry cleaning machines, changes in consumer fashions and fewer dry cleaners. For example, in Madison, Wisconsin, from the late 1950s to early 1960s, there were more than 60 separate listings for dry cleaners in the telephone directory at any given time, but by 2020, there were only about 12. Based on U.S. Census data, 87% of dry cleaners were still using PCE in 1980.[3] By the 1990s, in response to increased regulation and concerns about the environmental and health impacts of PCE, dry cleaners started shifting away from PCE back to petroleum-based compounds, silicone, carbon dioxide, and other alternatives. A 2014 survey reflected PCE use by 49% of drycleaners,[4] and a different survey found 60-65% of dry cleaners use PCE and the remaining use hydrocarbons or alternative solvents.[5]

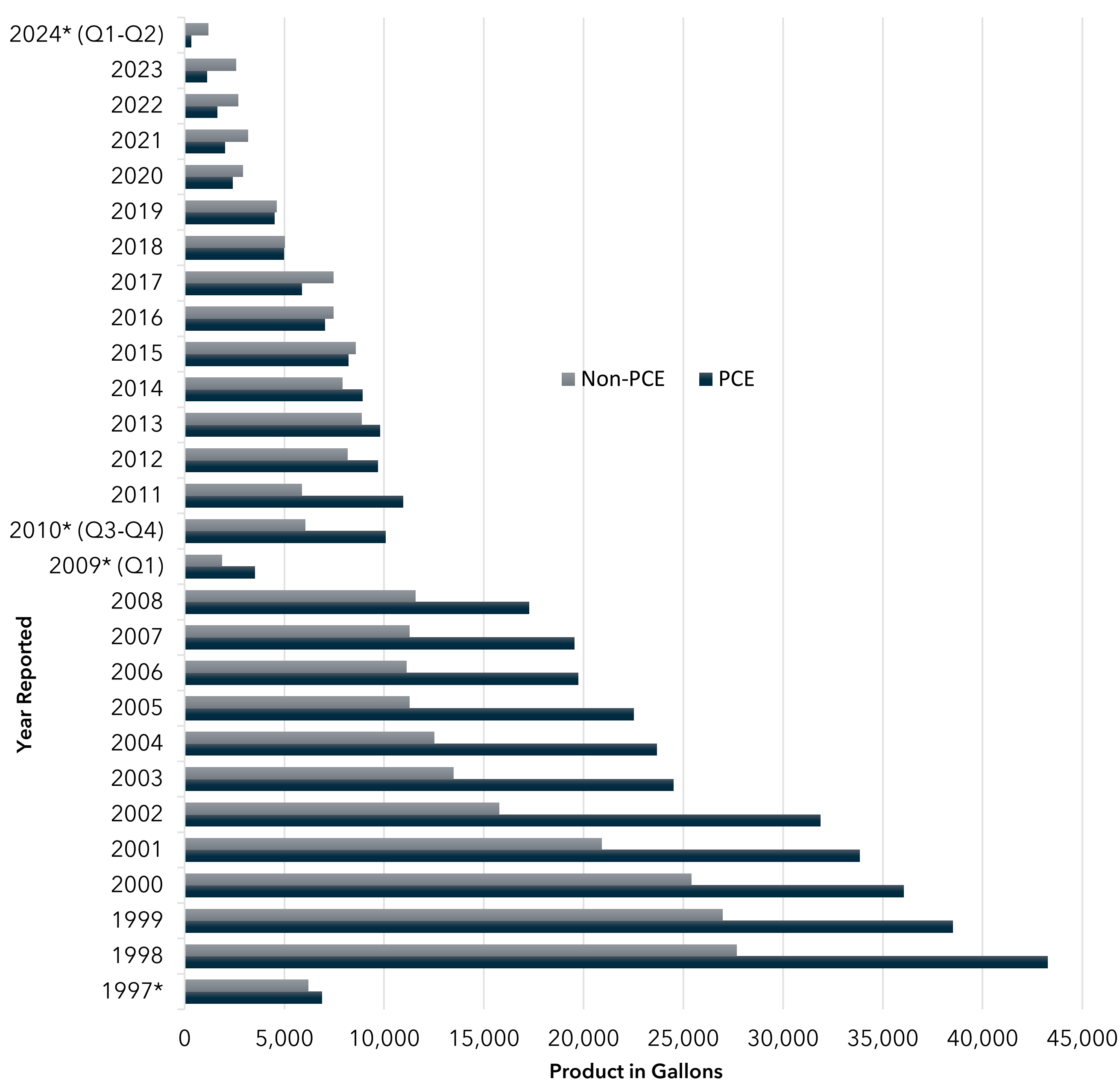
Figure C-1. PCE Use by Year by the Dry Cleaning Industry in the U.S.



[1] Stoddard solvent is composed of over 200 compounds.
[2] Chemical Engineering News 1963.
[3] USDC 1986.
[4] American Drycleaner 2014.
[5] EnviroForensics 2023.

Solvent use in Wisconsin reflects national trends. Figure C-2 shows the volumes of PCE and non-PCE solvents reported to the Wisconsin Department of Revenue by dry cleaners under the Dry Cleaner Environmental Response Program (DERP).[6] These data are based on volumes reported by solvent suppliers on their quarterly returns per calendar year. Quantities for filing years 2000 and earlier are based on data converted from spreadsheets (i.e., the accuracy of the data is unknown).

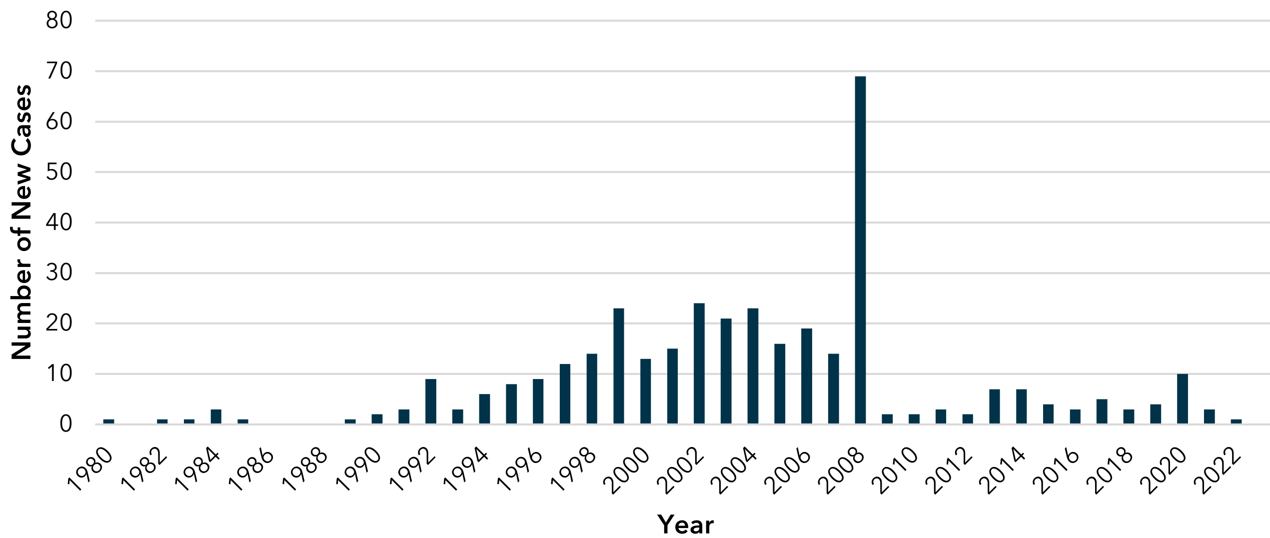
Figure C-2. Solvent Quantities Reported by Dry Cleaners in Wisconsin



*1997, 2009, 2010 and 2024 totals reflect partial year data.

[6] DERP is authorized under Wis. Stat. § 292.65 and Wis. Admin. Code ch. NR 169.

Figure C-3.New Cases Per Year from Dry Cleaner Operations



The start of the DERP reimbursement program provided incentive for dry cleaners in Wisconsin to investigate properties for historical discharges to the environment. The investigation and reporting of discharges from dry cleaners peaked just prior to August 2008 (see Figure C-3), when the program closed to new applicants. Historical discharges from dry cleaners in Wisconsin are now primarily discovered through due diligence investigations prior to property transactions. Based on a cursory review of historical phone books from Madison, Milwaukee and other Wisconsin cities, the DNR estimates there are thousands of historical dry cleaning locations where environmental investigations have not yet taken place.

C1.2 Dry Cleaning Operations

Dry cleaning operations have changed over time with the evolution of technology, waste management regulations and consumer demands. However, all dry cleaning operations included a means to deliver solvents, wash and dry the clothing, and then dispose of the spent solvents, wastewaters and solid wastes. Most dry cleaners incorporated ways to filter and re-use solvents, such as on-site distillation units and muck cookers, which were used to reclaim solvent from distillation sludge and filter residue.

C1.2.1 Solvent Delivery

Until the 1990s, solvent was delivered in bulk on trucks and pumped into the dry cleaner's underground or above ground storage tanks by a hose. Alternatively it was delivered in 55-gallon drums. Tanks and drums were placed in various locations throughout a property, not necessarily next to the dry cleaning machine. After the 1990s, solvent was mostly delivered by hand cart in small 5-gallon containers. Systems delivering PCE via closed loop/direct couple connections became available in 1993.[7]

C1.2.2 Dry Cleaning Machines

First generation: The first generation of dry cleaning machines were introduced in the 1920s. Clothes were cleaned in one machine, then transferred by hand to a drying machine. Solvent was released into the air or dripped onto the floor during transfer. The dryers were vented. First generation machines

[7] SCRD 2010.

were also called "transfer" machines. Transfer machines released about four pounds of PCE by vent and two pounds during transfer per 100 pounds of clothes cleaned.[8] The cleaning efficiency or solvent mileage (weight of clothes cleaned per unit of solvent) for first generation machines was about 1000 pounds of clothes cleaned per 100 pounds of PCE. An average neighborhood dry cleaning operation used about 50 to 100 gallons of PCE per month.[9] Table C-1 shows the cleaning efficiency of dry cleaning machines.

Changes to Dry Cleaning Machines with the Clean Air Act

After the introduction of the newest generation of machines, it took some time for the older machines to be replaced. Although the second generation machines came on the market in the late 1960s, 34% of dry cleaners still used first generation machines in 1991. The 1990 amendments to the Clean Air Act majorly impacted dry cleaner operations by preventing the opening of machines until vapor concentrations fell below certain concentrations. By 2000, only 4% of dry cleaners were using first or second generation machines,[10] and by mid-2008, transfer machines using PCE were no longer allowed.

Photo 2. First generation dry cleaning machine circa 1951. (Wisconsin Historical Society #70012)

Second generation: Invented in the late 1960s, washing and drying in second generation equipment took place in the same machine. Second generation machines were also known as dry-to-dry machines, since clothes entered and left the machines dry. Early models vented to the atmosphere.

Third generation: The third generation was introduced in the late 1970s and early 1980s. These dry-to-dry machines incorporated a refrigerated condenser to recover solvents and were the first non-vented, closed-loop machines.

Fourth generation: The fourth generation was introduced in the late 1990s and are the same as third generation machines with additional carbon absorption units to reduce solvent vapor concentrations in the drum of the dry-cleaning machine to below 300 parts per million (ppm).

Fifth generation: The fifth generation machines were introduced in the late 1990s and have sensors that do not allow the machine to be opened until solvent vapor concentrations are below 300 ppm.

[8] Mohr 2004.
[9] Doherty 2000.
[10] Eastern Research Group 2005.

Table C-1. Solvent Mileage by Machine Generation[11]

Equipment Generation	Lbs. of PCE Used per 1,000 Lbs. of Clothes
1st	78-100 lbs.
2nd	77-94 lbs.
3rd	20-40 lbs.
4th	10-20 lbs.
5th	10 -20 lbs.

Coin-operated (self-service) dry cleaning machines: Coin-operated dry cleaning machines introduced in 1960 had a small capacity of 8 to 12 pounds of solvent and used PCE (see Photo 3).[12] These machines were dry-to-dry and did not have a distillation unit. Spent solvent was purified by filtration. Self-service dry cleaning machines were similar in size to regular washing machines and were often found in self-service laundromats where water-based washing took place. Self-service dry cleaning machines were also found in dry cleaner facilities. In 1963, 7,000 coin-operated dry cleaning centers existed in the U.S.; and by 1976, there were 11,804. In 1979, of the 40,000 coin-operated laundromats (water-based washing), 15,000 to 18,000 were equipped with coin-operated dry cleaning machines.[13] Coin-operated dry cleaning machines were more common in rural areas not serviced by bulk dry cleaners.[14] The trend toward wash-and-wear clothing caused a slowdown in the growth of PCE use, but this slowdown was counterbalanced somewhat by the introduction of coin-operated dry-cleaning machines.[15]

Cleaning performance and safety concerns curtailed the use of coin-operated dry cleaning machines.[16] The cleaning performance of these machines was poor. There were also reports of fatalities due to PCE vapors remaining on dry-cleaned items. Coin-operated dry cleaning machines were banned in the U.S. in 1994.

Solvent had to be replaced often due to rudimentary filtration; solvent became discolored and did the same to the clothes. Consequently, dry cleaners discharged high volumes of spent solvent to sanitary sewers, a commonly accepted practice prior to its regulation. Dry cleaner operations with only coin-operated units were not eligible for DERP. (Wis Stat. § 292.65(1)(d) and (4)(a)). These dry cleaner operations were less likely to have been investigated but can present the same human health and environmental risks as traditional dry cleaners.

Photo 3. Coin operated dry cleaning machine (photo courtesy of Saskatoon Public Library)

C1.2.3 Wastewater

Several types of contact water were created during the dry cleaning process. Contact water is any water

[11] SCRD 2010, CARB 1996, Nat 'l Clothesline 2002.
[12] SCRD 2010.
[13] Morrison 2013.
[14] U.S. EPA 1995.
[15] Doherty 2000.
[16] In Milwaukee, there were 67 phone book ads in 1964 that listed self-service dry cleaning. By 1986, there were only five ads.

that contacts dry cleaning solvents (see SCRD 2010 for more information). Historically, contact water was discharged, typically into a sanitary sewer or septic system, but sometimes also discharged onto the ground, into storm sewers, and blind drains.[17] A study found that as late as 1988, more than 70% of dry cleaning operations disposed of contact water into sanitary sewers or septic systems.[18] At 70° F, contact water can have 150 ppm of PCE and wastewater also often contained pure solvent. At some sites, contact water was misted externally. Dry cleaners also commonly rinsed spent filters on site for reuse.

C1.2.4 Solid Wastes

Dry cleaners generated solid wastes such as lint, still bottoms, powder residue, spotting residues and spent filters. The Resource Conservation and Recovery Act (RCRA) of 1976 required that most of these waste streams be handled as a hazardous waste. However, most dry cleaners did not contract hazardous waste haulers for disposal of hazardous wastes prior to the mid-1980s. These wastes were often stored outside the building, disposed of on the ground and handled with the regular trash.[19] Some types of filters retained significant amounts of solvent when disposed of.

C2 Contamination Conceptual Model

There can be a great deal of uncertainty regarding the locations of discharges at sites where dry cleaning occurred in the distant past. Even if contamination did not reach the water table, sufficient contamination may exist beneath a foundation to result in VI. As discussed in Appendix A3.3, pinpointing releases using soil sampling is unlikely to provide much certainty given the often-limited aerial extent of releases. Vapor sampling will typically provide a more robust data set to identify the source areas.

Figure C-4 shows typical spill locations at dry cleaners.

Slow Drips Can Result in Large Releases
Even a small drip from a leaking gasket on a dry cleaning machine or metal degreaser can release a substantial amount of solvent in a small horizontal area. A once every five second solvent drip could release about 75 gallons of solvent in one year.

C2.1 General Considerations

The combined effect of solvent choice, machine efficiency and fashion trends resulted in a large volume of PCE moving through the dry cleaning industry from the 1940s to 2000. PCE was discharged to the environment due to solvent delivery practices, machine technology and waste and wastewater disposal practices. Dry cleaning locations that used PCE during this time likely have some degree of contamination, and could have significant contamination remaining even if they only operated for short periods of time. Based on estimates,[20] the average neighborhood dry cleaner operating first generation machines used hundreds to over a thousand gallons of PCE per year. A handful of neighborhood dry cleaners in the late 1950s would have used as much PCE as all dry cleaners in Wisconsin in 2019.

Even dry cleaners that only operated fourth generation machines had potential to cause significant impacts to the environment. At one such site, vapor concentrations in the sub-slab were measured at 22,000,000 micrograms per cubic meter (µg/m^3).

Site investigation results and photographs from the past show that historical dry cleaning operations do not resemble current operations. Sampling at known locations of dry cleaning machines and solvent tanks is

[17] SCRD 2010.
[18] International Fabricare Institute 1989.
[19] SCRD 2010.
[20] Doherty 2000.

logical; however, spills may have occurred anywhere within a space used by a dry cleaner. Contamination could also occur around other parts of the operation, such as a still or spotting table.

In the past, information obtained from interviews guided investigations to some extent. For example, a previous operator may have provided the location of a drum or spent filter storage. This information can be useful; however, at an increasing number of dry cleaner sites, the operations that caused the contamination often occurred decades ago. Recollections may be partially or fully inaccurate. At some locations, multiple individuals may have operated the dry cleaner over time. One owner may not be familiar with how others operated the facility. Spills caused by staff may not have been reported to the owner. The DNR recommends that a statement that something did not happen should be verified by sampling.

Photo 4. Back of dry cleaner machine where spent filters were rinsed out directly onto the floor for filter reuse as reported by the operator. Wastewater was left to seep into floor cracks, open cinder block wall or evaporate.

At an increasing number of sites, the building is repurposed, and the dry-cleaning facility is long gone, leaving no indication of where different dry-cleaning operations took place. Some information may be available from historical fire insurance maps and building records; however, these sources may not portray operations in detail and may not include the entire operational history. The location of many building features that can provide clues to contaminant distribution may have been different during operation. These elements include locations of current or former exterior doors and access, drains, sewer laterals, foundation elements, vents, and more. Even building additions may cover historical locations of exterior discharges.

The horizontal cross-sectional area of contamination can be small and difficult to find with vertical soil borings.

C2.2 Delivery

Bulk delivery of solvent was typical until the 1990s. It was common for solvent to drip onto the ground as the hose retracted from the drycleaner back to the truck. This mode of release is often not fully explored in investigations and can be difficult to find following building modifications and street upgrades.

C2.3 Service Doors

Entrances where solvent and wastes entered or were stored are a common focus of contamination. Dry cleaners may also have discharged contact waters or vents, washed filters, or dumped spent solvent near service doors.

C2.4 Dumpsters/Waste Storage

Historical dumpster and waste storage locations are important for investigation purposes due to historical practices. These may have been stored against the exterior of the building, in the corner of the property or other locations.

C2.5 Solvent Storage

Because of the larger volume of solvent used in earlier generations of dry cleaning equipment, solvent was stored in drums or large aboveground or underground storage tanks separate from the machine. Drum and tank locations may have been outside and multiple locations may have been used over time. In later generations of machines, smaller volumes of solvents were typically stored in tanks at the base of the machine.

Photo 5. Solvent storage within a dry cleaner.

C2.6 Machines

A survey performed by the Florida Department of Environmental Protection found that 56% of all discharges events were related to equipment maintenance and operation. However, larger volume discharges were more often related to solvent storage and transfer.[21]

C2.7 Sewers

Sewer disposal may result in leaks from the sewer system from the drains beneath the building to hundreds of feet from the property. Some types of sewer materials are more prone to leakage, such as older sewers constructed of clay, concrete or brick. Sewer cleaning can remove the colmation layer (*i.e.*, fine-grained materials and biofilms that build up on pipes) and increase leakage. Leakage out of the sewer system and contamination of soil and groundwater can occur in discrete zones along the sewer system. Leaks may occur where pipes have sagged, broken at joints, been compromised by tree roots or corroded from the solvent. Half-mile long plumes have resulted from small breaks in a sewer line.

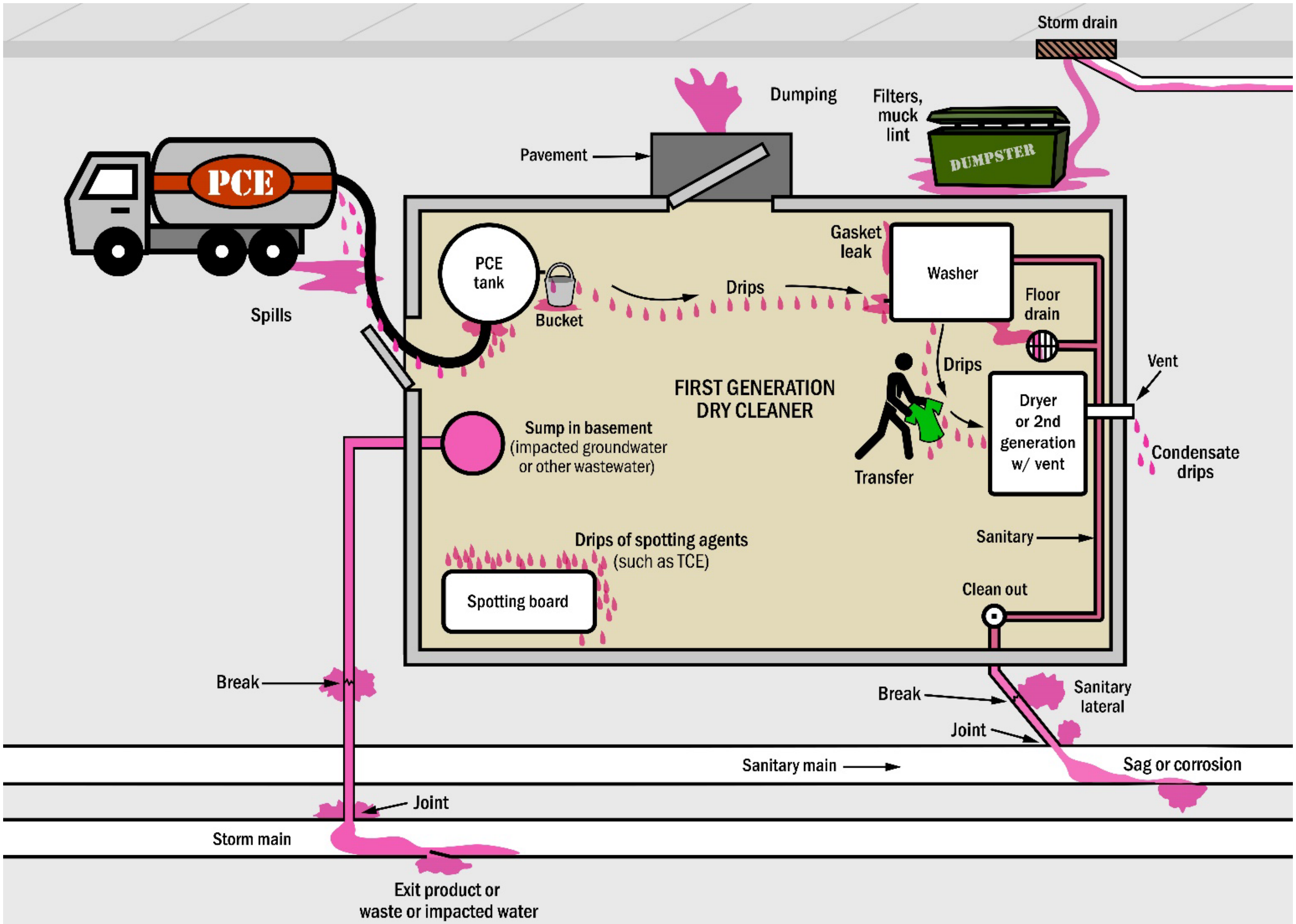
C2.8 Vents

Vent locations are often overlooked during investigations but can be significant sources of contamination.[22] The first two generations of dry cleaning machines were vented. Vents may have been on the roof or a wall. At 70 °F, the air can contain 26,000 ppm of PCE. In cooler weather, PCE condenses when it hits the cold outdoor air.

[21] http://astswmo.org/files/Resources/SCRD/Reported-Leaks-at-Florida.pdf.

[22] At one Wisconsin investigation, concentrations of PCE in soil and groundwater were in the hundreds of ppm beneath the vent.

Figure C-4. Typical Solvent Discharge Locations at Dry Cleaning Operations



C3 Other Operations with Chlorinated Solvents

C3.1 Background

The most used chlorinated solvents over the past 100 years include carbon tetrachloride (CT), PCE, TCE and 1,1,1-trichloroethane (1,1,1-TCA).[23] These compounds were used to manufacture a variety of products and as raw materials for production of other chemicals. The compounds were also widely used as cleaners and degreasers. Although CT and 1,1,1-TCA can cause a VI concern, TCE, and to a lesser extent PCE, generally pose the most significant VI risks at non-dry cleaner sites.

C3.2 Number of TCE Sites in Wisconsin

The DNR documents contaminants of concern (either individual contaminants or categories of contaminants) as searchable **Substances** in BRRTS. CVOCs and PCE have been documented as searchable **Substances** in BRRTS for many years. DNR added TCE in the searchable **Substances** in January 2019 to better communicate to users of our database when this particular contaminant is present at a site. At the time of publication, the DNR is in the process of reviewing historical site data and updating **Substances** in BRRTS to reflect whether PCE, TCE and/or other CVOCs were detected at sites to increase the accuracy of the database. Some of these contaminants may overlap at the same site. The DNR projects there could be over two to three thousand sites for each compound. Anecdotal review of site names and aerial photos for these cases indicates that these contaminants exist at a wide variety of property types and building uses and are not limited to typical industrial/manufacturing facilities. This broad occurrence may reflect the widespread use of these compounds, the former industrial and commercial uses of properties, or the migration of the chemicals from other properties. It is likely that thousands of historical releases have yet to be discovered. Figures C-5 and C-6 are maps of Wisconsin showing locations and density of sites in BRRTS having TCE as of October 3, 2024. The figures include open and closed Environmental Repair Program (ERP) and Leaking Underground Storage Tanks (LUST) sites. Data on these figures are not a complete representation of sites with TCE data submitted to the DNR.

[23] Doherty 2000.

Figure C-5. Statewide Distribution of Known Sites with TCE

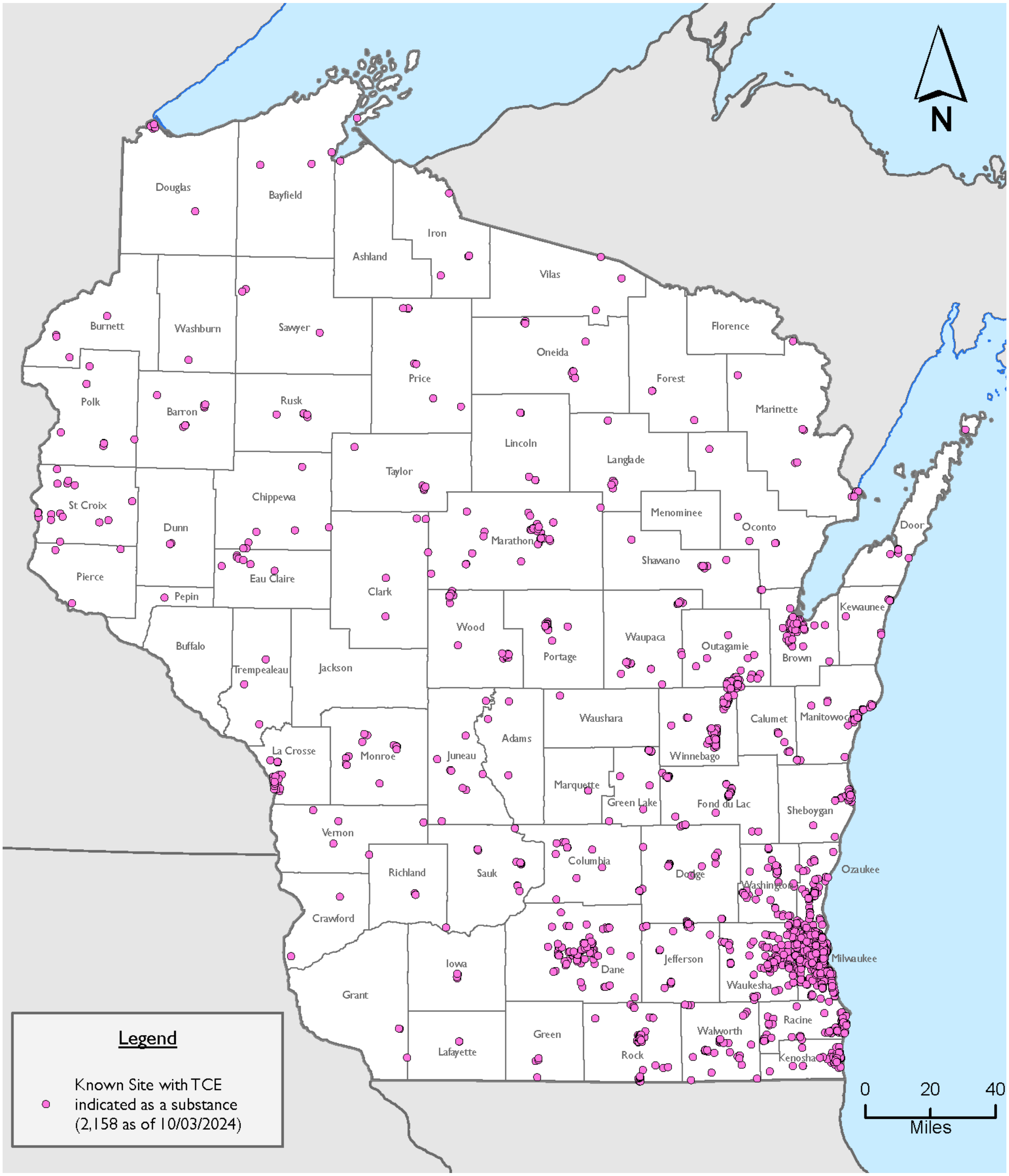
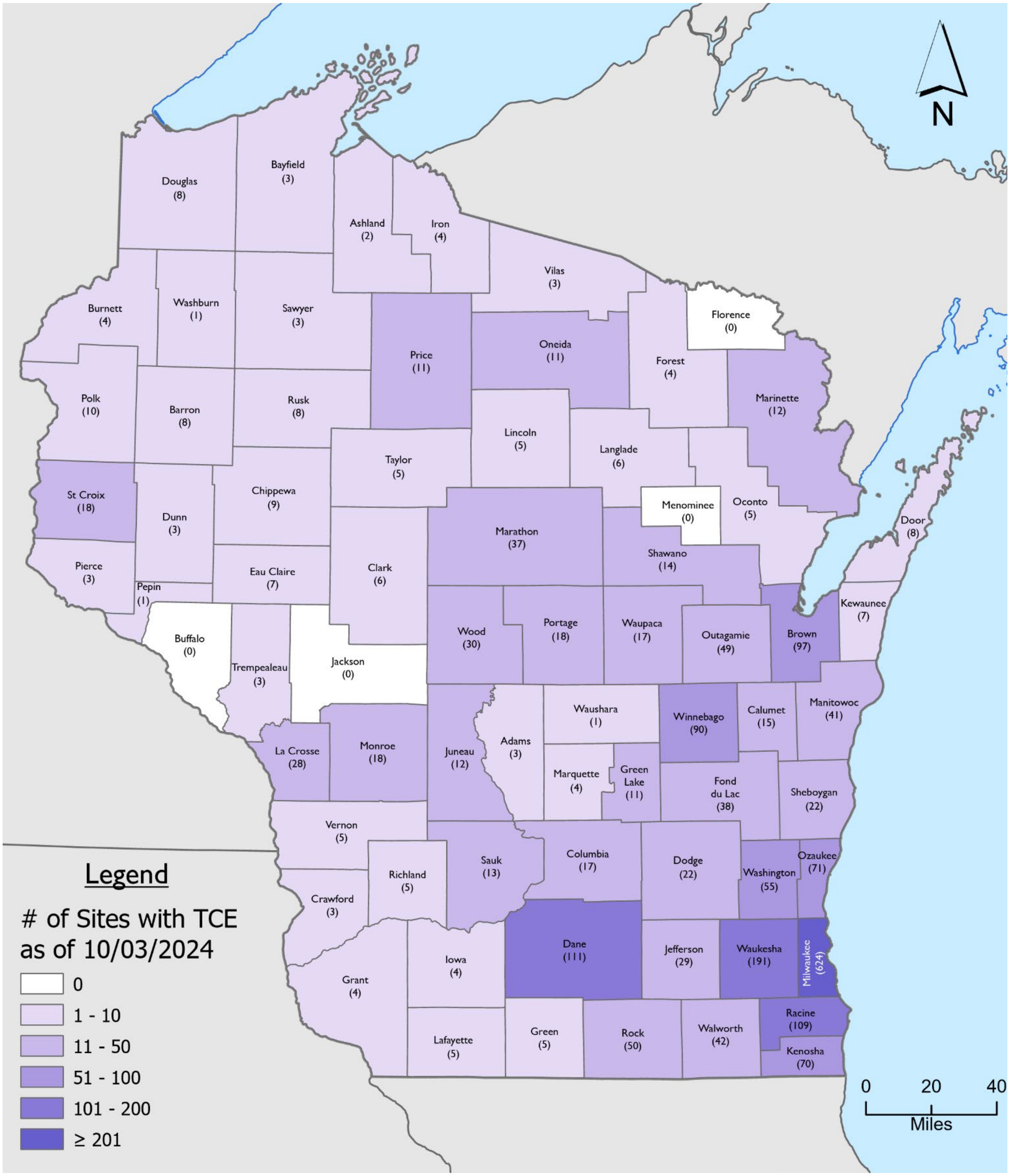


Figure C-6. Density of Known Sites with TCE by County



C3.3 TCE Vapor Degreasing

Although solvent dip tanks were sometimes used to cold-clean parts, vapor degreasing was the most common use of chlorinated solvents, particularly TCE. The vapor degreasing process uses solvent vapor to clean grease, oils, dust and dirt from fabricated parts. Solvents such as TCE are boiled in a degreasing unit to produce hot vapor. Parts are placed into the degreaser, and hot vapor condenses onto the parts, causing beading and dripping. The dripping action carries the contaminants away from the fabricated part, leaving behind a clean surface. After vapor degreasing, parts are suspended on a rack to drain the solvent. Vapor degreasing may take place in batches or as part of a continuous in-line system. In batch machines, each load, consisting of parts or baskets of parts, is moved into the machine after the previous load is completed. With in-line systems, parts are continuously loaded onto a conveyor or monorail that transfers them into the vapor degreaser and then out for cooling and drying.[24]

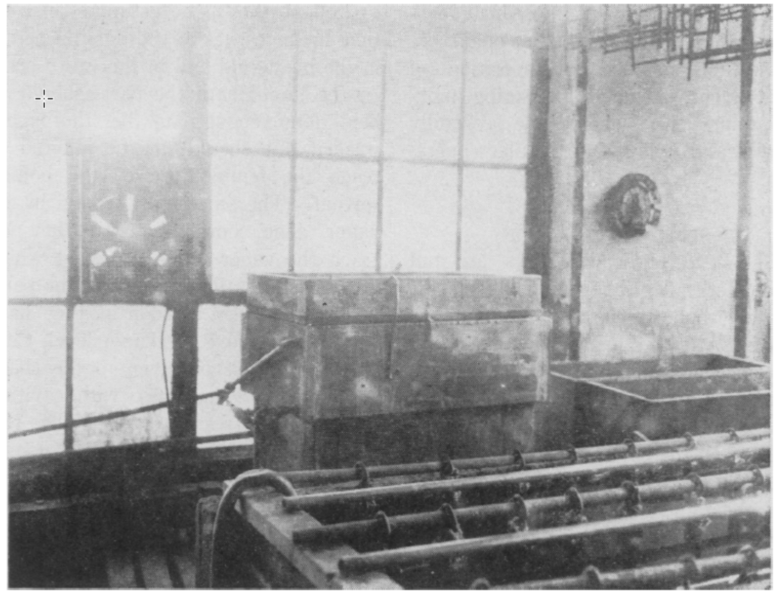


FIGURE II—Tank located by window and fan--high solvent loss

Photo 6. TCE degreasing tank (Harris, 1939)

C3.4 Use of TCE as a Degreaser in the U.S.

From the 1940s until 1980, 13 billion pounds of TCE was produced in the U.S., primarily for use as a degreasing agent in machine shops.[25] Use of TCE as a degreaser rapidly increased during the 1940s. In 1943, about 25,000 to 30,000 vapor degreasers operated in the U.S. By 1952, about 92% of the approximately 220 million pounds of TCE produced each year was used for degreasing. TCE production in the U.S. peaked in 1970 at about 600 million pounds in one year. Its use as a vapor degreaser began to decline, from 87% of TCE produced in the early 1970s to 42% in 1976. TCE was replaced with 1,1,1-TCA; however, environmental concerns related to the use of 1,1,1-TCA caused its use to decline after 1996. By 1991, 90% of TCE produced was used in degreasing, although U.S. production had declined to about 200 million pounds per year. The percentage of TCE used for degreasing has since declined; the U.S. EPA reported that of the 255 million pounds of TCE used in the U.S. in 2011, about 15% was for metal degreasing.

C3.5 Implications for Vapor Investigations

Compliance with environmental regulations mostly promulgated after the early 1980s and improved solvent handling practices have lessened the likelihood of spills. Most vapor investigations address spills from practices that occurred prior to the 1990s. Commonly, the current owners or operators of sites under environmental investigation have not used TCE and have little or no information about past use of TCE. Obtaining accurate information about the compounds, processes, and locations of solvent use is practically

[24] See Morrison 2013 for detailed descriptions of vapor degreasing.
[25] Morrison 2013.

impossible in many cases. Building ownership and production layouts may change considerably over time. Current best practices for vapor degreasing and solvent handling are far better and cannot be extrapolated to past operations. Former vapor degreasing practices included solvent delivery and storage, spills, water separator discharges, plumbing, leaky seals, drips from parts carried out of degreasers, distillation stills, and disposal of spent solvent and sludge.[26]

A survey in the 1930s found 0.3 to 15 gallons of solvent loss to occur per square foot of tank per 100 hours of operation.[27] Unless there is a high degree of certainty about the type, amount, and location of past solvent use, a conservative approach to surveying vapor concentrations is recommended. As discussed in Appendix A3.3, using soil sampling to pinpoint releases is unlikely to provide much certainty given the often-limited aerial extent of releases. Vapor sampling typically provides a more robust data set to identify the source area(s).

[26] Morrison 2013.
[27] Harris 1939.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix D – High Purge Volume Sampling Recommendations

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

High Purge Volume (HPV) sampling is an alternative sub-slab sampling method that can be used in large buildings that have intact, uniform foundations and suitable geological conditions. This method may not be suitable for buildings with cracked, deteriorating or complex foundations. Suitable conditions for consideration are discussed in more detail below. HPV sampling is not appropriate to evaluate preferential pathways. It is recommended that HPV sampling is viewed only as supplemental to standard discrete sub-slab vapor port sampling.

The following is recommended when conducting HPV sampling:

Confirmation Sampling*:* Prior to the HPV test, collect standard discrete sub-slab vapor samples (minimum of one location for each HPV test location) (Section 8.5.2).

Geologic Setting: Use HPV sampling only when native soils are much less permeable than the granular fill beneath the slab. Provide documentation.

Methane: Special considerations for safety are necessary if methane is present below the foundation slab near the explosive range or higher[1].

Extraction Point Location: To minimize atmospheric effects, place extraction points where the radius of influence of the extraction point does not reach significant foundation cracks, utilities, or the edge of the building. Typically, locating the extraction point 25 to 50 feet from one of these features is a sufficient distance, but verify with the pressure field extension (PFE) testing described below. Provide photographic documentation of the slab conditions in the area around each extraction point.

Extraction Point Construction:

- Core a 2-inch to 6-inch hole into concrete
- Remove the soil/fill to depth approximately 6-inches below foundation
- Set a ½-inch to 2-inch diameter slotted PVC well screen into hole below foundation
- Connect screen to riser pipe that extends approximately 1-foot above the floor. Do NOT use PVC glue to connect screen to riser
- Backfill around screen with soil or filter pack
- Seal the annular space above the screen with quick grout
- Allow grout to set at least 6-hours before sampling

Venting*:* Vent vapors to outdoor air.

Vacuum: Measure the amount of purge volume with a calibrated pump.

[1] NAVFAC 2023.

Leak Testing: Use a smoke pen to look for leaks during the first 2 to 5 minutes after the vacuum is turned on. Areas where smoke is visibly sucked into the sample train, port, or foundation slab indicate leaks.

Sample Collection: Collect samples using an evacuated canister with a flow controller that limits vapor flow to no more than 200 mililiters per minute (mL/min).

Measure VOCs with a photoionization detector (PID) and/or oxygen (O_2) and carbon dioxide (CO_2): Measure the vapor extracted from each sample point during HPV sampling to reveal whether outdoor air or indoor air is being collected (i.e., leaks). Baseline readings are collected at the start, and readings are taken continuously or periodically (e.g., every 5 minutes) throughout the remainder of sampling at each point. Interpret results as described below.

- **Decrease in PID readings and/or decrease in CO_2 and increase in O_2 -** Indicates less contaminated air is moving into the sample point, possibly due to leakage of ambient or indoor air or because lower concentrations are present below the slab at the outer edge of the capture zone. Other LOE (e.g., vacuum measurements) may be needed to interpret whether change is because of leakage or changing subsurface conditions.
- **Stable PID readings, O_2 and CO_2 -** Indicates uniform concentration of vapors within the capture zone of the sample, and leakage is unlikely.
- **Increase in PID readings and/or increase in CO_2 and decrease in O_2 -** Indicates higher levels of contamination present at a distance from the sample point, and leakage is unlikely. These results can be used to reveal hot spots of contamination below the slab.

PFE Testing: Measure the vacuum radius of influence by measuring the differential sub-slab/indoor air pressure prior to the test to establish a baseline, and then during the test at sufficient locations, particularly near the building edge or any suspected changes in foundation or subsurface conditions. Baseline readings are collected from each port before the vacuum is turned on, and differential pressure/vacuum readings are periodically recorded during sample collection. Measure the radius of influence at ports around one sample point, at a minimum, and around additional sample points when there are known or suspected changes in foundation or subsurface conditions that could affect the size of the capture zone.

Submit all documentation to the DNR to support data interpretation.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix E – Recommendations for Evacuated Canister Sub-slab Vapor Sampling

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

This appendix contains DNR recommendations for sub-slab vapor sampling using evacuated canisters. Use of 1-liter evacuated glass bottles may be an acceptable alternative (see Section 8.3.3). If using passive samplers to sample sub-slab vapor, follow recommendations from the manufacturer on port construction and sample collection. See Section 8.5.2 for additional recommendations.

Contents

E1 Port Construction

Sub-slab vapor port construction consists of drilling a small hole through a building foundation into the underlying soil. A brass or stainless-steel probe is placed in the hole and an airtight seal is created around the metal probe. The sealing material can be cement grout or other non-chemical reacting sealing material. The goal is to allow collection of a sub-slab vapor sample while preventing air movement around the vapor port. Protect the vapor port from any traffic that would dislodge the probe; flush mount covers or countersunk caps are preferable. The DNR recommends that the vapor port be constructed to allow for multiple samples over several months and securely sealed to prevent additional VI from the subsurface into the building. Measure the thickness of the foundation slab and record at each sub-slab sampling location to document site conditions.

Many practitioners utilize pre-manufactured probes with silicone seals that are hammered into the probe hole. Vapor ports may also be installed by drilling a small hole (~5/8" diameter) through the foundation into the sub-slab soil, then over drilling the pilot hole to create a 1" diameter hole about 1" to 2" deep into the foundation. The over drilling creates a ledge for the sampling probe and allows the concrete or other sealing material to be placed around the metal probe.

It is important to vacuum the concrete dust out of the hole. A small amount of non-VOC putty may be placed around the probe at the interface of the larger and smaller diameter holes to ensure that the cement does not seep below the probe and clog the pilot hole. After installation, allow adequate time for curing of the seal.

Allow sub-slab vapors to equilibrate prior to sampling by allowing the vapor port to "rest" one to two hours. Alternatively, purge the vapor port by removing volumes of air and screen the sub-slab vapors until PID readings are stable (no apparent increasing or decreasing trend). Vapor port locations must be documented and this information must be provided to property owners (and should also be provided to the DNR) when property owners are notified of sample test results (Wis. Admin Code § NR 716.14(2)(c)8.) and vapor port construction information must be provided to the DNR in the Site Investigation Report (Wis. Admin. Code § NR 716.15(2)(e), (4)).

E2 Leak Testing

Leak tests allow the sampling technician to determine whether leaks are present and to correct any conditions creating leaks prior to collecting the sub-slab vapor sample. Conduct two leak tests prior to each sub-slab sample to confirm for airtightness - one for the sampling train and one for the vapor port.

Leak testing methods must be documented when reporting results to the DNR (Wis. Admin. Code § NR 716.15(2)(e)). The DNR recommends collaborating with the DNR project manager prior to using a leak testing method other than those described below.

Test fittings connecting the tubing between the sub-slab vapor port and the collection container, usually an evacuated canister. These fittings, along with the probe seal, must be airtight or ambient air can leak into the evacuated canister and significantly bias the measured sub-slab vapor concentration results. Non-disposable fittings may be used for assembly of the sample train, shut-in testing or sampling. Document the fitting type (e.g., multiple-use fittings) and decontamination procedures applied for any multiple-use fittings that are not provided by the laboratory with the sample canisters.

Components of sample train include the following:

1. Sealed sample port with connection to inert tubing
2. Shroud with inlet opening to introduce helium gas and an opening for measuring helium concentration
3. Hand or electric pump with vacuum gauge to purge sample train and port and create vacuum on sample lines for shut-in test
4. Quick connect valve that allows access to the sample port to screen sub-slab vapor for helium, organic vapors, oxygen, and carbon dioxide, etc., as well as connection to the evacuated canister
5. Evacuated canister or other sampling container with flow controller and vacuum gauge; moisture and particulate filters may also be attached.

E2.1 Shut-in test

A shut-in test measures the airtightness of the fittings between the sample probe and the sample container. A vacuum gauge is connected to the sampling line between the sub-slab probe and the evacuated canister. Valves to the probe and evacuated canister are shut and a hand-pump or other device is used to remove air from the sampling line, inducing a vacuum in the line of 50 to 100 inches of water. When all the external valves to the sampling line are shut, the vacuum gauge should remain steady, indicating no leaks at any fitting, for at least one minute. Loss of vacuum indicates a leak, and fittings should be adjusted until the line can hold a vacuum.

E2.2 Water Dam Method

A water dam is a common method used to establish airtightness of probe seals. A small enclosure (e.g., a short section of a 2-inch PVC pipe) is sealed to the floor around the sub-slab vapor probe and filled with water. Alternatively, the vapor probe can be sunk below the grade of the floor, and the core-hole above the probe used as the casing to hold the water. If the water placed in the casing maintains a constant level, the test confirms that no leaks are present in the probe seal. If the water leaks through the probe seal, the probe should be removed, re-set, and re-tested or the hole abandoned and a new location chosen.

Water can permanently damage an evacuated canister; ensure that water does not enter the evacuated canister. Not all foundations are compatible with the water dam method; the foundation material may be uneven or may be covered with materials not conducive to standing water (e.g., carpet).

E2.3 Helium Shroud Testing

Helium is a non-toxic gas that is absent from the subsurface environment and easy to screen in the field. Helium gas is introduced to a concentration of 20% to 50% percent by volume into a shroud covering the sub-slab probe. The helium concentration inside the shroud is measured using a hand-held helium meter. A sub-slab vapor sample is withdrawn and screened with the helium detector. A helium concentration from the probe greater than 5% of the concentration from the shroud indicates a leak; the probe should be resealed and retested prior to sampling. A helium concentration from the probe less than 5% of the concentration from the shroud indicates that the probe is adequately sealed, and collection of the vapor sample can proceed. When using helium as a tracer, use technical grade helium of greater than 99% purity for leak testing.

Hand-held helium meters typically use a thermal conductivity detector that is not specific to helium. To eliminate the most common interferences, use a filter on the meter to remove water and hydrocarbons. If a false positive reading from the probe is suspected, helium can be added to the laboratory analysis of the evacuated canister to confirm that the probe seal had leakage of 5% or less.

E3 Sample Collection

After the leak and shut-in tests are performed, purge at least three volumes of air from the sample train. The sub-slab vapor is then usually screened for VOCs with a PID, and for oxygen and carbon dioxide, especially if PVOCs are suspected.

A sub-slab vapor sample is then drawn into an evacuated canister. Fit the canister with a flow controller that limits vapor flow to no more than 200 mL/min. A flow controller ensures that an excessive vacuum is not placed on the sampling probe. A flow rate of 100 to 200 mL/min of flow is recommended for sub-slab vapor sampling, meaning that a 6-liter canister will take 30 to 60 minutes to fill, and a 1-liter canister will fill in approximately 5 to 10 minutes. Use a vacuum gauge to verify and record vacuum measurements of sampling canisters before and after sample collection. Canisters should not be used if the initial vacuum reading is less than 25 inches of mercury. During sub-slab vapor sampling, the canister can be filled to zero pressure (i.e., the canister is completely filled and no longer drawing sub-slab vapor).[1] Canisters smaller than 6 liters are acceptable unless the 6-liter size is needed to achieve appropriate detection limits.

Take care to limit the release of purged sub-slab vapors into the indoor air space. Collect indoor air samples before sub-slab vapor sampling when practicable.

E4 Port Abandonment

The DNR recommends including plans for abandoning sub-slab vapor probes in the site investigation work plan. Abandonment consists of removing the probe and permanently sealing the hole. This may be achieved using neat cement (mix of rapid-dry Portland cement and water into a pourable slurry) with the surface of the abandoned hole made flush with the rest of the floor. If an access agreement is needed to gain access to the building, attempt to secure access for multiple sample rounds and future probe abandonment.

[1] This approach differs for 8- and 24-hour indoor air samples, for which some vacuum (follow laboratory recommendations for acceptable remaining vacuum) should remain in the canister at the end of the sample period to ensure that the sample was collected over the full 8 or 24 hours.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix F – Mitigation of the Vapor Intrusion Pathway

Related Guidance

DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

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Publication: RR-800

dnr.wi.gov

This document is intended solely as guidance and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

Tables

F1 Mitigation Goal and Requirements

Food for Thought
The best way to address vapor intrusion may be to remediate the source.

Vapor mitigation is comprised of engineered systems that interrupt the pathway of contaminant vapors from the subsurface into indoor air. Mitigation is not remediation; it does not reduce the mass and concentration of the contamination.

The DNR strongly recommends utilizing mitigators certified by the National Radon Proficiency Program (NRPP) or an equivalent national program to design, install and commission vapor mitigation systems (VMSs). See Section F2.2.2 regarding sub-slab depressurization systems (SSDS) and sub-membrane depressurization systems (SMDS) for additional guidance on selecting a qualified mitigator for any selected mitigation.

Construction Documentation
Construction documentation submittals must be prepared by or under the supervision of a professional engineer (Wis. Admin. Code § 712.07(3)).

Wis. Admin. Code chs. 708 and 724 address the design of vapor mitigation systems. Submittal of the mitigation system design for DNR review and approval is required *except for* simple radon-type SSDS (Wis. Admin. Code § NR 708.11(4)(b)). See Appendix G for a list of all deliverables relating to vapor mitigation.

The DNR has authority to assign continuing obligations (COs) at the time of an interim action, remedial action, or case closure approval under Wis. Stat. § 292.12(2). If a mitigation system is installed as an interim action under Wis. Admin. Code § NR 708.11, the responsible party (RP) or property owner must continue to operate the system until the DNR determines it is no longer required (Wis. Admin. Code § NR 724.13(1)(c)). The DNR will assign a CO to require operation, maintenance and monitoring (OM&M) of the system, including routine inspections. The DNR may also assign a CO to submit inspection logs to the DNR (Wis. Admin. Code § NR 727.05(1)(b)3.); this typically occurs for sites with chlorinated volatile organic compounds (CVOCs).

Both the RP and the property owner are responsible for the VMS, including OM&M of the system, under Wis. Admin. Code § NR 724.13(1)(c). The VMS is generally the responsibility of the RP until case closure under Wis. Admin. Code ch. NR 726 and then the responsibility is typically transferred to the property owner at closure, unless the RP and property owner enter into an alternate agreement that is approved by the DNR and placed on the DNR's database (Wis. Stat. § 292.12(5)(c)). In unique circumstances, the DNR may assign responsibility to the property owner prior to closure. See *DNR Case Closure Continuing Obligations: Vapor Intrusion* (RR-042) for additional information on vapor intrusion (VI) COs.

F2 General Steps in Vapor Mitigation

Vapor mitigation consists of the steps listed below.

Step 1 - Select an appropriate mitigation response.
Step 2 - Design and install the mitigation response.
Step 3 - Commission the system: performance verification testing and establish baseline conditions.
Step 4 - Develop an OM&M plan.
Step 5 - Perform OM&M until no longer required by the DNR.
Step 6 - Decommission the system.

Indoor Air Quality – The Primary Measure of Success
The ultimate measure of success of a VMS is the ability of the system to limit the intrusion of contaminant vapors into indoor air such that contaminant concentrations below vapor action levels (VALs) are achieved and sustained. Along with system performance metrics, such as pressure field extension (PFE) testing for an active SSDS, the DNR recommends that commissioning includes indoor air sampling, in most cases. The recommended schedule for confirmation indoor air sampling is shown in Table F-1.

F2.1 Select an Appropriate Mitigation Response

F2.1.1 Factors for Selecting a Mitigation Response

Acute vs. Chronic Health Risk and Timeframes: How quickly mitigation should be implemented depends on whether there is an acute risk that requires immediate action. Risk is based on the land use, contaminants of concern (COCs), concentrations of contaminants in the indoor air, sub-slab vapor, and conduits and receptors present in the building. Table 2 recommends timeframes for implementing mitigation, which informs the selected mitigation option. The DNR recommends implementation of rapid response measures (RRMs, see Section F2.2.1) as indicated in Table 2 or if site conditions may delay implementation of standard mitigation such as an SSDS.

Building Conditions: Mitigation options in existing buildings may be limited by the construction methods and layout. A wider selection of mitigation options may be available when constructing a new building, which may include the incorporation of a granular base layer, horizontal pipe network or equivalent venting layer, and a chemically resistant vapor barrier beneath the foundation.

Building Size: For smaller buildings (generally < 30,000 square feet (sf)) the DNR recommends installing a mitigation system that is effective across the entire building slab. For larger buildings, mitigation may be limited to the areas of contamination when a sufficient subsurface evaluation is completed to demonstrate that the unmitigated area does not exceed the vapor risk screening levels (VRSLs) and preferential pathways are not present in this area. The DNR recommends sampling in accordance with the recommendations in Figure 4 and Table 2 to verify the location of the mitigation area. An RP may consider the cost to mitigate the entire foundation versus performing the amount of sampling and evaluation necessary to limit mitigation to a smaller area.

Subsurface Conditions: The gas conductivity of materials under the foundation and the separation between the water table and foundation are key subsurface conditions that determine whether an SSDS is feasible. The presence of sub-grade materials having sufficient gas conductivity to allow propagation of a vacuum are needed for an SSDS. An SSDS is not likely to be effective as a sole mitigation strategy if the water table is near or contacts the foundation or if native clay soils are located immediately under the slab. Section F2.1.2 gives recommendations for situations with subsurface conditions that are not conducive to an SSDS.

Coordination with Remedial Actions: Temporary mitigation measures may be needed to protect building occupants until a remedial action can be performed that causes vapor concentrations to decrease or a mitigation system can be designed and installed.

F2.1.2 Mitigation Options

Submittal of the mitigation system design for DNR review and approval is required *except for* simple radon-type SSDS (Wis. Admin. Code § NR 708.11(4)(b)). Submit the request for review and approval with the appropriate fee under Wis. Admin. Code ch. NR 749.

Did you remember to conduct remedial action?
When mitigation is needed to interrupt the VI pathway into the building, a remedial action that reduces the mass and concentration of the source(s) of VOCs is required prior to closure (Wis. Admin. Code § NR 726.05(8)(b)1.)

Active Sub-Slab Depressurization System (SSDS): An SSDS uses sub-slab suction pits or sub-slab perforated piping connected to a powered fan to create a low pressure vacuum under the building foundation slab. The system exhausts the collected vapors to the outside air to prevent potential intrusion of vapors into the building. The vacuum may also be applied to a sump, drain tile, or hollow block wall.

Active Sub-Membrane Depressurization System (SMDS): An SMDS is similar to an SSDS but uses a chemical vapor barrier for buildings without a competent concrete slab (e.g., buildings with a dirt floor crawl space). An SMDS may also be used in new construction; a chemical vapor barrier is placed prior to installation of the foundation.

Active Sub-Slab Ventilation System (SSVS): An SSVS is similar to an SSDS; however, instead of using a pressure field to collect and route contaminated vapors, an SSVS sufficiently dilutes contaminant concentrations below the building by advective air flow. An SSVS typically consists of a venting layer (e.g., a layer filled with porous media like sand or pea gravel) and a pipe array with fresh air intakes and discharge vents on the opposite sides of the building. The contaminated soil vapor migrates to the pipe array and the fan system vents it to the atmosphere.

An active SSDS is the DNR's preferred long-term mitigation method.

Active Indoor Air Building Controls: This mitigation approach uses heating, ventilation, and air conditioning (HVAC) system to either increase the air exchange rate (AER, which dilutes contaminants) or to maintain a consistent positive indoor air pressure relative to sub-slab soil (prevents vapors from entering). This approach can be used to temporarily reduce indoor air concentrations; however, it is not recommended as a long-term solution for the following reasons:

- Increased ventilation may cause occupant discomfort and greatly increase energy costs.
- If not done correctly, increased ventilation may cause negative indoor air pressure relative to sub-slab soil and increase the potential for VI.
- Maintaining sufficient dilution throughout occupied spaces may be challenging.
- Maintaining positive pressure in spaces with exhaust vents, such as bathrooms, can be difficult and costly in buildings that are not designed to maintain positive pressure conditions. Even buildings designed to maintain a positive pressure relative to outdoor air may have locations of negative pressure in relation to sub-slab soils due to cold air returns, mechanical ventilation and other features.[1]
- This approach requires consistent operation of systems with complex settings that may be subject to human interference.
- Diffusive flow through the slab will continue and may be problematic when sub-slab

[1] Shea 2017, 2018.

contaminant concentrations are high (e.g., >100,000 micrograms per cubic meter (µg/m^3)) even if positive pressures are maintained relative to the subsurface.
- Compliance over a long period of time may be difficult. Long-term stewardship requirements in the form of COs to maintain the performance of these systems may include many HVAC settings and pressure monitoring requirements. In addition, modifications to the HVAC system may be discouraged.
- This approach is not suited to residential buildings, which do not typically have HVAC systems that sufficiently control air handling.
- Mitigation must consistently maintain concentrations below the VALs, especially when contaminants with short-term exposure risks are present, such as trichloroethylene (TCE).
- Even when an overall positive interior pressure is maintained, barometric pressure changes may cause accumulated contaminant vapors within foundation cracks to move into indoor air (see Section A2).

Parking Structures: Enhanced building construction and ventilation techniques for vehicle exhaust in enclosed parking structures may partially or fully mitigate chemical VI from the sub-surface. An AER sufficient to address vehicle exhaust is not guaranteed to completely mitigate chemical VI, especially when CVOCs are present. In addition, preferential pathways within the structure (e.g., elevator shaft, stairwells, utility conduits) may result in VI to an overlying building.

Chemical Vapor Barriers: Chemical vapor barriers, including sheet and spray-applied membranes, may be placed beneath a building during new construction to reduce the migration of contaminated vapors into the occupied building space. Although the DNR does not recommend chemical vapor barriers as a stand-alone vapor mitigation approach due to the difficulty in verifying installation and performance after building construction, they may enhance the efficiency and performance of an active VMS. Even when used with an active mitigation system, performance verification with sampling and diagnostic testing from beneath the barrier is needed (Wis. Admin. Code § NR 724.15). If chemical vapor barriers are used without appropriate ventilation, sub-slab vapor contaminants may accumulate resulting in higher contaminant concentrations. If any portion of the barrier fails, the accumulated contaminants at higher concentrations may enter the building.

Passive Ventilation: A passive ventilation system redirects soil gas or sub-slab vapor from below a building to the atmosphere without using a powered fan. Passive ventilation relies on temperature differences and wind to create a slight negative pressure in the riser pipe. At best, passive systems induce a slight negative pressure at the riser compared to an energized fan. During some weather conditions, a positive pressure can occur in the pipe relative to the sub-surface. If sub-slab vapor sampling in new construction indicates that contaminant concentrations are below the VRSL, such a system can be voluntarily operated; however, the DNR has rarely approved passive ventilation if sub-slab CVOC concentrations are above the VRSL, or sub-slab vapor concentrations indicate acute risks.

Indoor Air Treatment: Indoor air treatment removes contaminants from indoor air using a filter media, such as granular activated carbon, contained within a portable powered filtration unit, or a filter in an in-duct HVAC-mounted system. Indoor air treatment does not prevent VI and is not a stand-alone or long-term mitigation approach; it is typically used as a RRM to temporarily reduce indoor air concentrations below acute risk levels or VALs until long-term active mitigation can be designed and installed.

Conduit Mitigation: Conduit mitigation typically consists of taking interim measures to prevent contaminant vapors from entering occupied spaces from the building's plumbing system and reducing the concentration within the plumbing system through ventilation, whole-building vapor traps, or other measures.

Emerging Technologies: The DNR recommends contacting the DNR project manager prior to pursuing emerging technologies.

F2.2 Design and Install the Mitigation Response

The DNR recommends RPs retain persons with specialized knowledge and training to design mitigation systems that address chemical VI and encourages use of appropriate design standards and following best management practices for the mitigation system being installed.

A qualified mitigation contractor is key to success.
The DNR strongly recommends retaining chemical vapor/radon mitigators certified by the National Radon Proficiency Program (NRPP), or an equivalent national program, to design and install VMSs. NRPP-certified mitigators are specially trained and must follow industry standards developed by the American Association of Radon Scientists & Technologists (AARST) and accredited by the American National Standards Institute (ANSI) along with continuing education to maintain their certification.

Additionally, the DNR recommends reviewing cost estimates and interviewing mitigators about their experience prior to selection. A mitigator may have NRPP certification but be specialized in mitigating radon at owner-occupied single-family residences, which is not equivalent to mitigating large multi-family or industrial buildings for chemical VI.

A website listing NRPP-certified mitigators that have self-registered with the Wisconsin Department of Health Services (DHS) is available at: https://www.dhs.wisconsin.gov/radon/radon-proficiency.htm. Another source to search for NRPP-certified mitigators is the NRPP website, available at: https://nrpp.info/pro-search/.

Mitigation systems installed by underqualified contractors may fail to meet minimum best practices. Systems in Wisconsin have been constructed with fans located *inside* occupied spaces, piping that *allowed water accumulation*, and/or exhaust stacks located *very near* air intakes, venting exhaust *downward*, resulting in questionable performance and protection of indoor air quality. These errors result in additional expenses for the RP and lengthen timeframes for protecting occupants from VI.

Not all contractors advertising as "mitigators" meet the basic requirements for protection of public health. The DNR recommends an inspection of older installations or installations not performed by an NRPP-certified mitigator for conformance with current best management practices and standards. An NRPP-certified Soil Gas Mitigation Compliance Inspector may also be qualified.

When system modifications are needed, the changes must be documented (Wis. Admin. Code §§ NR 724.13(4) and NR 727.07(4)); substantial changes may require recommissioning to meet case closure criteria (Wis. Admin. Code §§ NR 726.05(4)(a) and (e)) and revisions to the OM&M Plan to verify the VMS remains protective (Wis. Admin. Code § NR 724.15(3)(h)).

DNR recommendations are provided in Table F-2, which focuses on SSDS, chemical vapor barriers, and parking garages. For design recommendations and standards for less commonly implemented measures, refer to the Interstate Technology & Regulatory Council (ITRC) documents discussed below or contact the DNR project manager.

The DNR recommends consulting the following entities for further information on mitigation system design:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides resources for best practices relating to indoor air quality (www.ashrae.org).
- American National Standards Institute / American Association of Radon Scientists & Technologists (ANSI/AARST) - maintains standards for mitigation of many types of buildings, including existing homes, multifamily buildings, schools, large buildings and new construction. ANSI/AARST's standards address both radon and chemical VI (https://standards.aarst.org/#pb).

- U.S. EPA Clean-Up Information, Vapor Intrusion Mitigation (https://clu-in.org/issues/default2.focus/sec/Vapor_Intrusion/cat/Mitigation/).
- ITRC provides fact sheets and other resources through its online interactive directory (go to itrcweb.org and search "vapor intrusion"). Topics include CSMs, public outreach, rapid response and ventilation, design considerations, active mitigation, passive mitigation, post-installation verification (i.e., commissioning), OM&M, remediation and institutional controls (i.e., COs), and exit strategies.

F2.2.1 Rapid Response Measures (RRMs)

RRMs include any actions taken to quickly reduce or interrupt indoor air contaminant concentrations until a long-term mitigation system can be designed and installed. RRMs are used to address an acute health risk when high indoor air concentrations occur and/or sensitive occupants are present in a building (see Table 2). RRMs include the measures below.

Additional RRM information from ITRC.
ITRC provides fact sheets for RRMs through its online interactive directory (go to itrcweb.org and search "vapor intrusion"). Useful topics include:

- Rapid response and ventilation for mitigation
- Preferential pathway sealing and ad hoc ventilation
- Indoor air treatment
- HVAC modification

Sealing Foundation Penetrations: Sealing foundation penetrations can quickly reduce VOC concentrations in indoor air and enhance the effectiveness of other mitigation measures. Foundation penetrations include cracks and gaps in poured concrete, fieldstone walls and block foundations, gaps around sumps and floor drains, and utility conduit penetrations. Finished basements can prevent full inspection of the foundation and slab. A portable instrument, ideally one that measures VOCs in the parts per billion (ppb) range, can help locate vapor entry points. The entire surface of the foundation can also be coated with a masonry paint or sealer. ITRC and ANSI/AARST standards provide recommendations for chemical VI.

Conduits: If an investigation reveals that vapors are entering the occupied space through conduits, several actions can be implemented quickly during the evaluation of additional conduit mitigation measures (see Section F2.2.5).

Floor Drains: Floor drains may have a plumbing trap with a water seal that leaks out or evaporates during periods that the drain is seldom used. Without a water seal, the drain may create a preferential pathway for vapors directly into a building, especially in bathrooms with exhaust fans and rooms with vent hoods (e.g., school science room) that create a negative pressure. The following strategies may prevent floor drains from becoming a preferential pathway:

- Use of a low vapor pressure trap filling liquid that won't evaporate (e.g., vegetable grade oil or baby oil)
- Periodically adding water to the trap
- Installing a trap primer that automatically adds water to the traps
- Installing a one-way valve that allows liquid to move downward but does not allow vapors to move upward
- Sealing unused floor drains with concrete or grout (if allowed by plumbing code)

Find plumbers licensed in Wisconsin through the following Wisconsin Department of Safety & Professional Services website: https://licensesearch.wi.gov/.

Other Plumbing: Seldom-used sinks may also have p-traps that dry out. This issue can be addressed through the actions listed for floor drains above. Additionally, check toilets and replace dried-out wax rings. Older buildings may have deteriorated fixtures and plumbing alterations that do not meet plumbing codes where vapors can enter the building. The DNR recommends working with a licensed plumber that can perform a smoke test to locate where vapors may be escaping the sewer piping.

Sumps: A basement sump may directly connect contaminated soil or groundwater to indoor air. Seal sumps with a gasketed, air-tight cover that facilitates pump access. Sumps may need to be ventilated to the outside to prevent advective flow of contaminant vapors. Take appropriate steps to avoid interfering with the sump's ability to perform its water control function. In addition to sealing, sumps may need to be plumbed to the sanitary sewer if the sumps discharge liquid with contaminants above specific concentrations (i.e., above Wis. Admin. Code ch. NR 140 standards) to the land surface or storm sewer. Such actions must comply with any applicable local ordinances and state regulations.

Ad Hoc Ventilation: Ad hoc ventilation means opening windows, doors, vents or installing fans within a structure to reduce indoor concentrations of VOCs by mixing and diluting indoor air with outdoor air. Ad hoc ventilation is appropriate as an immediate measure in some circumstances, such as following a residential fuel oil release. This option is generally available only during comfortable temperature, humidity, and precipitation conditions, and is appropriate during the evaluation of other RRMs or long-term mitigation options. This option is not viable if there is a source of contaminants in outdoor air.

Increase outdoor air input (by opening windows on the lower level of the structure) as much as indoor air output (such as opening windows on the upper levels of a structure, operating ventilation fans, window fans) to avoid reducing indoor air pressure of the building relative to sub-slab, which can increase soil vapor flow into the building.

HVAC Modification: As described in Section F2.1.2, despite the concerns with modifying HVAC systems as a long-term strategy, it can be useful in the short term. Modifications can either increase the AER and dilute vapors that enter or increase building pressure relative to the sub-slab soil and inhibit vapors from entering. As with ad hoc ventilation, avoid increasing indoor negative pressures near the foundation slab. HVAC modification can be complicated, and it is recommended that all areas in the building are considered before modifying an HVAC system (e.g., offices, bathrooms, kitchens). The DNR recommends retaining an HVAC contractor when modifying an HVAC system.

Find registered HVAC contractors and licensed engineers in Wisconsin through the Wisconsin Department of Safety & Professional Services website: https://licensesearch.wi.gov/.

Indoor Air Treatment: Available air treatment systems include both in-duct and portable models. The most effective adsorption medium for air filtration for TCE contamination is activated carbon[2]. The fan in an in-duct HVAC-mounted filtration system must run continuously for the system to be effective.

Portable air purification units (APUs) using activated carbon adsorption may successfully reduce vapor concentrations. Portable APUs are readily available and can often be delivered within a few days; however, closed doors and other circulation obstructions can limit the effectiveness. These units can be placed where concentrations are highest; however, portable APUs are not always able to reduce indoor air concentrations to below the VAL. A study done in Massachusetts found TCE concentrations ranging from 8 to 120 µg/m^3 to be reduced by 60 to 80%.[3] However, it took at least 10 days for the maximum reduction to occur. Portable APUs could not reduce concentrations below the VALs in residential apartment units.

[2] U.S. EPA 2017.
[3] Fitzgerald 2016.

When reduction of indoor air concentrations is desired within a matter of days (e.g., 2.1 μg/m^3 when TCE is the contaminant and women who are or may become pregnant are present), it is recommended that indoor air is sampled with a quick lab turn-around time to verify effectiveness within 48 hours after installation, and again at two weeks if permanent mitigation has not yet been installed.[4]

When using indoor air filtration, consider the following:

- Some indoor air contaminants (not associated with the VI pathway) may compete for available adsorption sites, lessening the removal of contaminants of VI concern.
- High humidity and high temperature impact treatment effectiveness. Water vapor can be a significant competitor for adsorption sites. Including a desiccant (e.g., zeolites) can help.
- Indoor air monitoring is necessary to evaluate system effectiveness and potential for contaminant breakthrough.
- Desorption may occur under various conditions and when a filter is replaced; filters should be replaced outside of occupied spaces when feasible.
- Fans run continuously, increasing electrical costs and noise. Occupants may turn off noisy fans.
- Dispose of used filters in accordance with local, state, and federal requirements.

The DNR recommends indoor air treatment as a short-term mitigation method (i.e., two to four weeks) in acute risk situations.

F2.2.2 Sub-slab Depressurization Systems and Sub-membrane Depressurization Systems

Most long-term mitigation systems are sub-slab depressurization systems (SSDSs). The major design elements of an SSDS and sub-membrane depressurization system (SMDS) are listed below.

Conductive Layer Beneath the Foundation or Membrane: To function effectively, a layer of sufficient gas conductivity must exist that allows a vacuum beneath the foundation. This layer can consist of sandy soil, a coarse base material, or granular or plastic venting constructed beneath a new building. To some extent, lower conductivity materials can be addressed with more extraction points.

Vapor Tight Foundation: A vapor-tight foundation is achieved by adequately sealing the foundation slab or, if the foundation is in poor condition or nonexistent (i.e., a dirt floor), by applying a chemical vapor barrier (i.e., a membrane). When using a chemical vapor barrier, it should cover the entire floor and be sealed to foundation walls, piers, extracting piping, and other penetrations.

Energized Fan: A fan creates a vacuum within the pipe network that extends in the sub-surface or other extraction point (e.g., block wall, sump). Place fans outside of occupied spaces and in easily accessible locations for routine inspection and maintenance.

Pipe Network: The pipes conduct vapor from the extraction points upward and exhausts the contaminated vapor at the exterior of the building away from windows and other openings. Place exhaust pipes at specific distances from opening and air intakes to allow exhaust up to the atmosphere.

Fan Placement
The DNR strongly discourages placing fans in unfinished attics that are not frequented by occupants. ANSI/AARST standards allow for this placement for radon mitigation; however, the potential health risk resulting from fan failure in a chemical VI setting is higher. Attic placement may also pose accessibility issues, complicating annual inspections. When feasible, and if vandalism is not a concern, mitigation fans should be placed on the exterior of the structure.

[4] DHS 2021 and DHS 2022. See Appendix H.

Operational Monitoring System: Commission systems after installation to ensure that a negative pressure field is created under the portion of the building where VRSLs are exceeded, in either sub-slab vapor or groundwater. Commissioning involves measuring the sub-slab to indoor air pressure differential. When a system is installed that meets the necessary performance guidelines (see Section F2.3), gauges, alarms, or telemetry systems are installed to provide confirmation that the system continues to operate as installed over the long term. All systems should have a continuous display device (e.g., a manometer pressure gauge or electrical amperage gauge) to show the specific vacuum that the fan is producing. The operating vacuum can then be compared to the vacuum produced at installation to verify the system is operating correctly.

Operational Monitoring with Active Notifications and Telemetry: Best management practices and ANSI/AARST standards include installation of active notification monitors that include audible and visual alarms on all active systems to immediately notify an occupant when the fan fails. Telemetry units that continuously monitor system operating parameters (e.g., fan operation, system differential pressure, ambient pressure, temperature, humidity) remotely notify an operator when a system is either not functioning or is not operating optimally. Telemetry systems can provide early warning of system failure by monitoring fan performance and other parameters. Some units allow for continuous monitoring of sub-slab to indoor air pressure. These measurements can reveal whether building or sub-slab conditions have changed (e.g., a rising water table prevents pressure field extension) to the extent that they affect system performance and increase potential indoor air risks from VI.

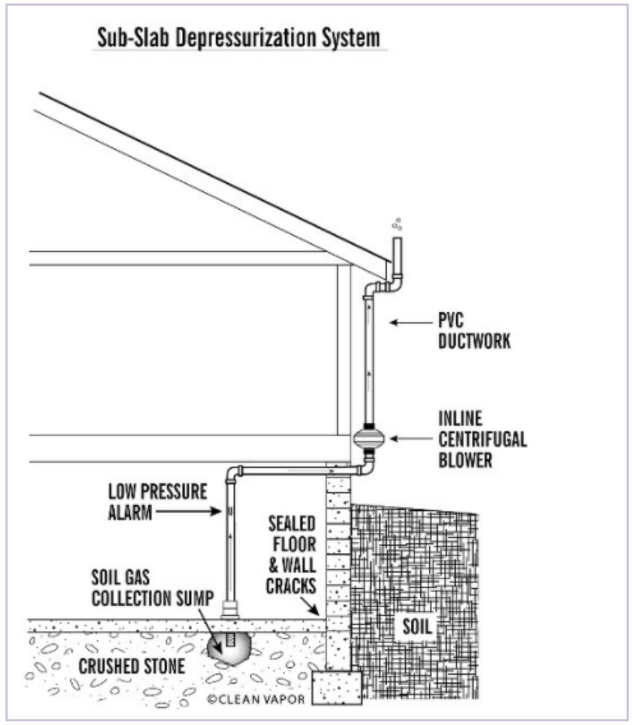


Figure F-1. Schematic of an SSDS

The DNR recommends:

- Active notification (i.e., audible notification that is clear and distinct, visual light notification that is vividly observable, or notification by telemetric means, such as by email or other electronic communication) for all active VMSs; and
- Telemetry and backup power systems where both of the following are present:
  - The mitigated building is used for multi-family residential (or any other land use where site specific conditions warrant); and
  - Prior to mitigation, TCE was detected at or above the VAL and/or the VRSL, or another compound was detected at acute risk levels in indoor air or sub-slab vapor.

Additional information regarding active notification and telemetry is available on the DNR website. Go to www.dnr.gov and search "vapor active notification."

High Water Table: A water table intersecting the foundation of the building must be addressed (typically by installing a dewatering system) before an SSDS can be installed. Sometimes it is clear during the investigation that the water table intersects the foundation of the building (e.g., based on water table elevation in nearby wells, water encountered during installation of sub-slab ports, wet foundation). However, a rising water table may not inhibit the functioning of the system until years after

SSDS installation. A manometer or an alarm, while useful for indicating fan disfunction, may not adequately indicate when a rising water table interferes with the pressure field; a telemetry system that continuously monitors system performance is needed to provide this level of assessment. Systems with differential pressure sensors in different areas of the building can improve verification. Consider installing a telemetry system if the water table is within five feet of the foundation at the time of SSDS installation.

F2.2.3 Chemical Vapor Barrier

Chemical vapor barriers are designed to prevent VOC-contaminated soil vapor from entering buildings and are different than vapor/moisture barriers used in conventional building construction. Chemical vapor barriers are not a stand-alone vapor mitigation approach. Chemical vapor barriers intended to address VOCs are generally installed above a permeable layer that allows soil vapors to migrate freely to active vent piping. They may be installed beneath a concrete slab, as a replacement for a concrete slab when constructed over a dirt floor as part of a SMDS, or to seal specific building features, such as an elevator pit (see Figure F-2). The particular use of the chemical vapor barrier will dictate design specifications, which include resistance to chemical vapor transmission, resistance to chemical degradation, strength, constructability, and conditions after installation (e.g., potential for equipment damage, potential damage from rebar installation, plumbing changes post barrier installation). Below are the major design and construction elements of a chemical vapor barrier.

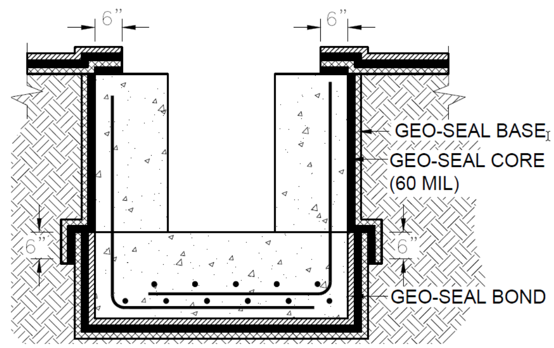


Figure F-2. Detail showing chemical vapor barrier sealing of an elevator pit

Membrane: Membranes designed for chemical VI maintain integrity during construction activities and are tested for the COC at concentrations present at the building. Using a membrane with a thickness of 60 to 100 millimeters may help reduce the potential for punctures during construction activities (e.g., cutting or grinding of rebar just above the barrier, installing concrete forms, dropping tools, foot traffic) or during the installation of the slab after the membrane is in place[5].

Protective Layers: Protective layers include geotextiles that are placed below and sometimes also above the membrane to protect the membrane layer.

Building Design: Integrate the chemical vapor barrier into all building plans and involve all professionals (e.g., architect, construction manager) to ensure they are aware of the importance of its function. The performance of the barrier relies not only on the specification of the membrane but the method by which the membrane ties into other building features including internal column terminations[6], utility penetrations, seams, grade breaks, exterior wall terminations, horizontal penetrations, vapor sampling ports, and elevator pits. Elevator pits are critical due to the cyclical negative pressure created at the base of the shaft by the movement of the elevator car and the potential vapor pathway between floors. The design and construction of the chemical vapor barrier in the elevator pit must be robust; waterproofing admixtures should be considered in concrete used in elevator pits.

5 ITRC 2007.
6 Internal column penetrations, and particularly, proper preparation of all areas prior to taping, if this aspect is part of the design.

Construction/Installation: Manufacturers of chemical vapor membrane systems have stringent quality assurance / quality control (QA/QC) standards for installation. These standards include ensuring manufacturer-recommended overlap at seams, complete welds connecting sheet materials, and effective sealing of utility penetrations through the membrane. Generally, manufacturers require a trained, experienced and certified installer to perform installation (some manufacturers provide installer certification or offer third party inspection services and warranties) to comply with the warranty. The DNR recommends observation of the installation of the slab above the vapor barrier by a qualified environmental consultant to ensure that the concrete and other contractors do not penetrate the vapor barrier after installation. Post-installation modifications of utility pipes that penetrate the membrane, rebar cutting, dropping of nails, dragging of geotextiles, spilling of solvents, and cracking due to cold weather and other installation issues may result in unacceptable indoor air quality (i.e., above VALs), which may affect the ability to secure an occupancy permit from a local agency.

Coordinate with all Contractors
Communication between the certified membrane installer, environmental consultant, construction manager, and other sub-contractors is important to maintaining the integrity of the chemical vapor barrier. For example, last-minute plumbing alterations not communicated to the installer may penetrate the chemical vapor barrier and create a breach in the membrane and void the warranty.

Testing: Quality control testing verifies the integrity of the barrier after installation. Smoke testing is a common method of testing membrane integrity. It consists of pumping smoke beneath the membrane, checking for smoke penetrating the membrane, and patching areas of observed smoke penetration. Additional smoke tests should be considered if rebar is installed or if other membrane breaches may occur prior to pouring concrete. See ITRC for additional information and resources (go to itrcweb.org and search “vapor intrusion”).

F2.2.4 Parking Structure

Newer mixed-use and multi-family residential buildings commonly feature lower-level parking garages. Parking structures generally consist of two types:

- **Above Ground Open-Air Parking Structure:** Above ground, open-air parking structures generally provide sufficient ventilation to prevent VI into the occupied portions of the building above the parking structure. However, specific components of the above ground open-air parking structure may present an increased VI risk, including any stairwells, elevator shafts, and utility penetrations that extend from either ground surface or below ground surface up into the occupied building space.
- **Underground and/or Enclosed Parking Structure:** Enclosed parking structures typically consist of fully enclosed floors, either single or multi-level, beneath a building. These structures are usually underground/below grade but sometimes are located at ground-floor or higher. Enclosed parking structures are designed to ventilate exhaust fumes from vehicles. In typical designs, parking garages maintain negative pressure relative to the overlying building and/or exchange in fresh air to the garage space. These designs prevent automobile exhaust from accumulating to unsafe concentrations within the garage and prevent air in the garage from flowing into the occupied spaces in the overlying building. These features can also prevent VI into the overlying building; however, to prevent VI, is the DNR recommends considering additional factors (see Table F-2). Designing a new parking structure to account for VI may be more efficient than modifying an existing structure. Existing buildings with a parking structure, or renovated buildings that will add a parking structure, require scrutiny to adequately address VI. The type and concentrations of contaminants will be factors to consider. For example, a site with concentrations of TCE many times the VRSL merits more scrutiny than a site with contaminant concentrations posing a chronic concern, where the contaminant level is just

above the VRSL (e.g., benzene concentration less than double the VRSL). An SSDS may be installed beneath the slab of the parking structure for additional protection or may be needed to achieve concentrations below VALs.

Parking Structure Design Considerations for Vapor Intrusion Mitigation

The DNR recommends that a licensed mechanical engineer or registered HVAC contractor provide an evaluation that considers the items below.

Parking Spaces: The air handling inside the parking structure is typically designed to comply with local building codes and indoor air standards such as ANSI/ASHRAE 62.1, Sections 5.15 and 6.5. Compliance with these standards alone can result in an interior pressure in the parking structure that is lower than the sub-surface pressure, inducing entry of sub-slab soil vapors. To prevent VI, the design must either minimize the entry of soil gases through sealing the slab and balancing exhaust air with makeup air or prevent soil vapors in the parking structure interior from entering occupied spaces by installing barriers and maintaining lower pressure in the parking structure than in occupied spaces. Air handling in a parking facility creates a temporally variable pressure and flow dynamic. It can be difficult to measure and assess pressure relationships between a ventilated parking space, sub-slab soils, and overlying and adjacent occupied spaces. Confirmation air quality sampling of indoor air over time can ultimately confirm that the system is protective.

Parking Space Envelope and Accessory Spaces: A primary concern with parking structures is whether contaminant vapors can bypass active ventilation, through walls, stairwells, elevator shafts, utility penetrations, or into accessory spaces (e.g., offices, waiting rooms, ticket booths, elevator lobbies). These possibilities can be investigated and mitigated separately as needed.

See Table F-2 for recommendations on documenting parking garage usage to prevent VI. For more information on using parking structures to mitigate VI, refer to: *Parking Facilities and Vapor Intrusion Mitigation*, February 22, 2019, available at https://www.pca.state.mn.us/sites/default/files/c-rem3-06i.

F2.2.5 Conduit Mitigation

Contaminant vapors may exceed VALs within the plumbing system of an occupied building. The first step in addressing VI through utility conduits is preventing vapors from entering the occupied spaces by protecting buildings from sewer gases (see Section F2.2.1).

Best practices to keep contaminant vapors from entering the plumbing system of a building from the sanitary sewer lateral, or to address other conduits have not been established. Discuss mitigation strategies with the DNR project manager prior to implementation. These measures can limit future VI through conduits.

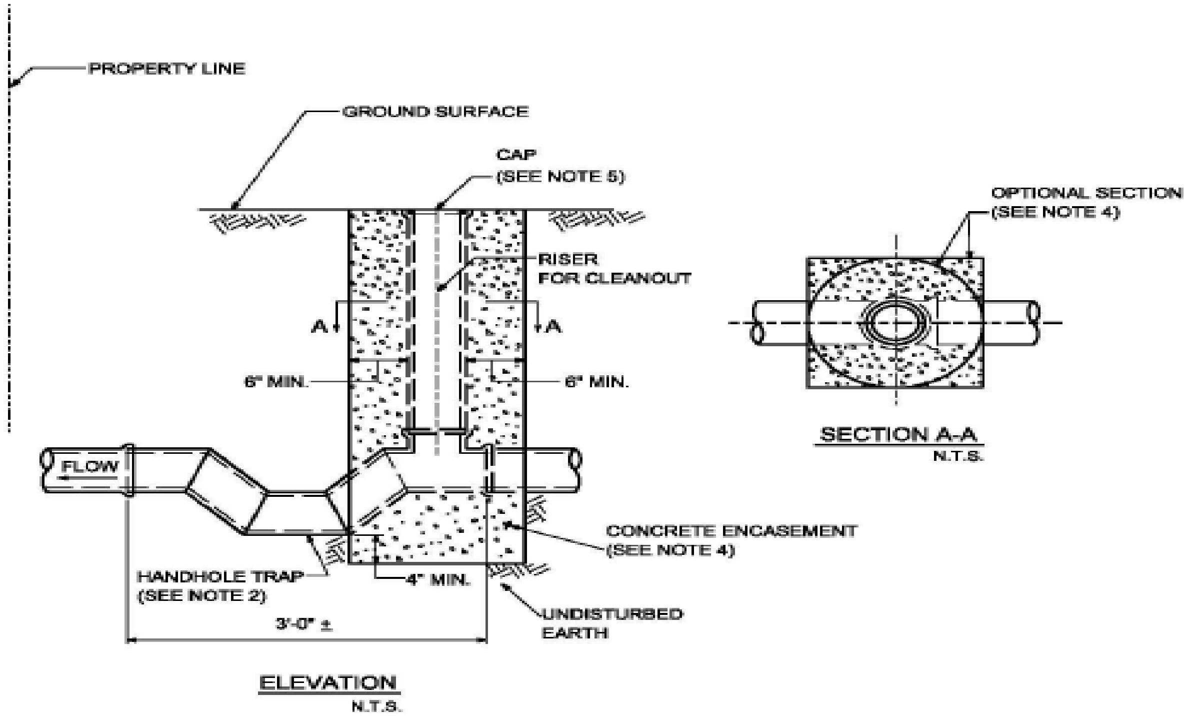
If utility conduits are determined to be preferential pathways for vapor, mitigation may include the following strategies:

- Venting or depressurizing utility bedding, plumbing cleanouts or manholes[7]
- Relining or replacing conduits to prevent contaminant entry
- Relocating conduits away from contaminated soil or groundwater
- Installing a carbon filtration system
- Installing a gas trap/siphon between the sanitary sewer main and the building (see Figure F-3)[8]

7 Nielsen 2017.

[8] U.S. EPA Region 9 has used this approach as an interim measure to reduce indoor air concentrations from conduits; however, the long-term performance is unknown.

Figure F-3. Gas Trap Siphon, City of San Diego, 2015



F2.2.6 Other Mitigation Measures

Measures other than those described in this section may be proposed; the DNR recommends submitting a system design workplan with a review fee (Wis. Admin. Code ch. NR 749). Prepare site-specific performance verification plans to demonstrate that the system meets or exceeds all design criteria (Wis. Admin. Code § NR 724.15(2)). In the plan, identify the design criteria, performance verification parameters, and the technical rationale for the selected parameters (Wis. Admin. Code § NR 724.11(7)).

F2.2.7 Special Cases

Contaminated Groundwater Contacts Building: In some cases, VI occurs due to contact between VOC-contaminated groundwater and a building foundation. Vapors volatilize from the contaminated water directly into the indoor air. To mitigate VI in these cases, first, prevent the contaminated water from contacting or entering the building foundation or drain tile, if possible. Often, preventing this contact requires pumping water away from the foundation. Discharging this contaminated water may require characterization and permitting. After dewatering the area surrounding the foundation, install additional vapor control technologies if needed to interrupt the vapor pathway. If dewatering is not feasible, constructing an aerated floor above the slab may be an option.[9]

Low Conductivity Soils Beneath Building: Soils with low gas conductivity beneath a building (e.g., tight clay with no granular material) may prevent installation of an SSDS. Consider other approaches, such as installing an aerated floor above the slab.[10]

SVE as Mitigation: An SVE system is a remedial action that targets a contaminant source area in unsaturated soil to reduce mass and concentration. An SVE system typically includes extraction of

[9] See the Interstate Technology Regulatory Council (ITRC) website for more information; go to itrcweb.org and search "vapor intrusion."
[10] See the Interstate Technology Regulatory Council (ITRC) website for more information; go to itrcweb.org and search "vapor intrusion."

contaminated soil gas at a greater depth than a traditional SSDS that focuses on redirecting soil gas around a building envelope. However, an SVE system installed to address a contaminant source area directly beneath a building (either in shallow soil and/or at depth beneath a building envelope) can serve as an SSDS to also *mitigate* sub-slab vapors, if intentionally designed. An SVE system that acts as both remediation (i.e., reduction of the mass and concentration of the contaminant) and mitigation (i.e., interruption of the vapor pathway) must be designed, commissioned, and monitored to meet the needs of both a remedial action and a mitigation system. Some additional considerations for combined remediation and mitigation systems are:

- Mitigation systems are typically operated at low vacuums to create slightly negative pressure under the slab. SVEs are typically operated under much higher vacuums to effectively remove greater pore volumes from large areas in short periods. Stronger vacuums under a slab, if placed too close to the foundation of a building, can draw contaminants from source areas (e.g., soil, groundwater, conduits), causing higher concentrations under the slab and increasing the risk of VI. Evaluate and monitor for this risk in a remedial design report.
- Evaluate the effect of higher vacuums on the HVAC system of an adjacent building, particularly the potential for back-drafting.
- Consider the effect of noise on occupants of the building. See ITRC for additional information and resources (go to itrcweb.org and search “vapor intrusion”).
- A site with an active SVE system is unlikely to meet the conditions of case closure (Wis. Admin. Code § NR 726.05(9).

F2.3 Commission the System: Performance Verification Testing and the Establishment of Baseline Conditions

Commissioning provides the information needed to demonstrate that the vapor pathway has been mitigated or interrupted, which is a requirement for case closure where the VRSL was exceeded (Wis. Admin. Code § NR 726.05(8)(b)). Complete commissioning for each system and ensure that the site-specific commissioning plan meets the objectives below.

Performance Verification: Demonstrate that the VMS meets its design criteria. Detailed performance verification guidelines for active depressurization, chemical vapor barriers and parking garages are summarized below and detailed in Table F-2. Performance verification for other systems should include parameters suitable for the system. (Wis. Admin. Code § NR 724.11(7).)

Baseline Conditions: Record site conditions corresponding to successful mitigation (Wis. Admin. Code § NR 724.15). Submit performance verification and baseline condition documentation in a construction documentation report (Wis. Admin. Code § NR 724.15). The DNR recommends recording baseline conditions on the system piping (e.g., date of installation, initial manometer reading).

Timeline: The DNR recommends initiating commissioning immediately after installing a VMS. Commissioning demonstrates the effectiveness of a VMS over changing seasonal and atmospheric conditions. The process can last from a few months to over a year, depending on site conditions and whether the VMS needs modifications to satisfy performance criteria.

A documentation report for a VMS must be submitted to the DNR within 60 days after the date that construction is complete (Wis. Admin. Code § NR 724.15(1)). The DNR considers mitigation system construction to be complete when commissioning is finished, and no further system modifications are needed. The DNR recommends providing updates to the DNR project manager during commissioning.

F2.3.1 Indoor Air Sampling Recommendations for Commissioning

Table F-1 provides recommendations for indoor air sampling during commissioning.

- **General**: Repeat indoor air sampling at the same locations used during the site investigation. Focus on locations where concentrations were near or above VALs, lowest-level occupied spaces, and spaces near potential preferential pathways (e.g., stairwells, elevators, sumps).
- **Parking structures**: Perform indoor air sampling on the first level of the occupied space above the parking structure, and within stairwells, elevator pits, and other occupied accessory spaces. Sampling in the lowest level of the parking structure may also be appropriate.

All sampling results must be reported to the DNR within 10 business days of receipt (unless otherwise determined by the DNR, Wis. Admin. Code § NR 716.14(2)-(3))

Table F-1. Indoor Air Sampling Recommendations for Commissioning

Situation	Recommendations[a]
After implementing RRMs	• Collect 8-hour (in worker settings) or 24-hour duration samples within 48 hours and analyze using a quick lab turnaround time of 24 to 72 hours. • Perform additional sampling events depending on results and length of operation of the RRM. Typically, another sampling event within two weeks with a normal TAT, unless a long-term mitigation system has been installed. • Perform monthly sampling events with a normal turnaround time until a long-term mitigation system is installed.
After implementing long-term mitigation	**For TCE**

	• If TCE concentrations in indoor air attain or exceed the VAL during the site investigation, or when the VMS is installed during sampling (see Section 7.2):
	    o If women who are or may become pregnant are present, concentrations of TCE attain or exceed three times the VAL, or for combined investigation and mitigation, sample within seven days. Collect 8-hour (in worker settings) or 24-hour duration samples with a quick lab turnaround time of 24 to 72 hours. Repeat at a minimum every seven days until the VAL is achieved.
	    o In other situations where concentrations of TCE attain or exceed the VAL, sample within 30 days. Collect 8-hour (in worker settings) or 24-hour duration samples with a normal lab turnaround time. Repeat at a minimum every 30 days until the VAL achieved.
	    o In addition, collect at least two longer duration sampling events[b] during the winter assessment period.[c]
	• If TCE concentrations in indoor air did not exceed the VAL during the site investigation, conduct at least one longer duration sampling event during the winter assessment period.[c]

	For all COCs

	• If the contaminant concentrations in indoor air attain or exceed the VAL during the site investigation or when the VMS is installed during sampling (see Section 7.2):
	    o Sample within 30 days by collecting 8-hour (in worker settings) or 24-hour samples with normal lab TAT. Repeat at a minimum every 30 days until the VAL achieved.
	    o Residential Setting:[d] Collect two longer-duration sampling events[b] during the winter assessment period.[c]
	    o Non-Residential Setting:[e] Collect one longer-duration sampling event during the winter assessment period.[c]

	• If the indoor air concentration did not exceed the VAL during the site investigation:
	  o Residential Setting:[d] Collect one longer-duration sampling events during the winter assessment period.[c]
	  o Non-Residential Setting:[e]
	    ▪ Collect one longer-duration sampling event during the winter assessment period[b] if any COC was above 50% of the VAL during investigation.
	    ▪ Other situations: building specific.

Notes:

a. Do not sample indoor air for a COC that is still in use.
b. See *Sample Duration* in Section 8.5.3
c. **The winter assessment period is December 1 to March 31.** In lower-risk situations when one sampling event during the winter assessment period is recommended, collect samples any time during the winter assessment period. In higher-risk situations when multiple rounds of sampling are recommended, conduct the initial round as early as possible during the winter assessment period and additional sample rounds later in the season (see also Table 2, Note d). Sampling during different portions of the season may build confidence in indoor air quality results. If the site investigation indicated that the highest vapor concentrations occurred outside the winter assessment period, the DNR recommends additional sampling that focuses on the conditions that caused the results to be higher. The higher concentrations outside of the winter assessment period may be related to building operation, water table conditions, meteorological factors or other site-specific factors.
d. **Residential setting** means any dwelling designed or used for human habitation, and includes educational, childcare and elder care settings (Wis. Admin. Code § NR 700.03(49g)).
e. **Non-residential setting** means a setting other than a residential setting, used for commercial or industrial purposes (Wis. Admin. Code § NR 700.03(39m)).

F2.3.2 Sub-slab or Sub-membrane Depressurization

A primary performance metric for an SSDS or SMDS is confirmation that the system is creating adequate PFE across the building floor slab(s) where mitigation is needed. The installation contractor should perform post-mitigation diagnostic testing to confirm the system is operating effectively, using the schedule in Table F-2. For new construction, testing should be done under typical building operating conditions (*i.e.*, when construction is complete and the HVAC system is operating).

F2.3.3 Chemical Vapor Barrier

See Table F-2.

F2.3.4 Parking Structure

See Table F-2.

F2.3.5 Existing Sub-slab or Sub-membrane Depressurization System

A previously installed SSDS or SMDS for radon may offer some protection from potential chemical VI; however, radon systems are not generally commissioned to the extent needed to be protective of public health in accordance with interim action requirements for chemical VI (Wis. Admin. Code § NR 708.11(3)(a)) and the quality of the design and installation may be uncertain. The mitigator may not have been qualified to install a system for chemical VI and installation may not have met the basic best management practices outlined in ANSI/AARST standards.

If the RP cannot rule out the possibility of VI into an occupied building by applying screening guidelines (see Sections 2.4 and 2.5), the evaluation must include: sub-slab vapor sampling to determine the presence and concentration of vapors below occupied buildings (Wis. Admin. Code §

NR 716.11(5)(g)) and indoor air sampling if needed to determine the impact of VI on occupied structures (Wis. Admin. Code § NR 716.11(5)(h)).

See Section 7.2 if considering installation of a VMS during sampling. If access is denied, follow the recommendations for best effort in Section 4.5.

If the building has an SSDS or SMDS for radon already in place, the DNR recommends collection of a sample from each riser as well as the required sub-slab samples, without interrupting or modifying the system. The number and locations of sub-slab vapor samples should follow the recommendations in Figure 3.

If sampling indicates that sub-slab vapor concentrations exceed the VRSL at any time during the investigation, activate and commission the system according to recommendations in Table F-2, document construction, and develop an OM&M Plan (Wis. Admin. Code §§ NR 708.15(3)(k), 724.13(2), 724.15, 724.17(2)). The DNR recommends either an NRPP-certified mitigator or equivalent, or an NRPP-certified Soil Gas Mitigation Compliance Inspector that has chemical VI experience completes a re-evaluation of the system design and that the system is upgraded to comply with best practices (e.g., by replacing a fan near the end of its lifespan, adding an active audible alarm, adding labels and baseline vacuum readings as appropriate).

If sampling indicates that indoor air concentrations exceed the VAL at any time during the investigation follow the recommendations in Table 2.

If sampling does not indicate either sub-slab concentrations exceed a VRSL or indoor air concentrations exceed a VAL, contact the DNR. The operation of a radon system may not allow an accurate assessment of sub-slab concentrations of the COC; however, interrupting the operation of the system may allow soil gases to enter the structure. The DNR will work with the RP, DHS and the building owner to discuss options that protect occupants from exposures to both radon and the COC.

Table F-2. Mitigation Design, Installation and Commissioning Recommendations

The DNR recommends including and documenting the following elements for each type of VMS:

Active Mitigation Systems	
Design and Commissioning Elements	
Type of system	SSDS, SMDS, SSVS, other (describe)
Design and installation standards	e.g., ANSI/AARST SGM-SF-2023
Contact Information	For environmental consultant/ designer/ installer/ commissioner(s), include the contact person, company, address, telephone, and email
Qualifications	For environmental consultant/ designer/ installer/ commissioner, provide NRPP or equivalent national program certification number, professional engineer, registered HVAC contractor, licensed plumber, other (describe).
Barrier	• Sealing performed: utility penetrations, foundation cracks, sumps, foundation sealant (such as a waterproof coating), expansion joints, other (describe) • Chemical vapor barrier (describe) **Note:** The DNR recommends a sealed barrier between the subsurface and indoor air for a depressurization system to be effective and to run efficiently.
Extraction Points	e.g., sump, foundation pit, block wall, crawl space, other (describe)

New Construction	Include any elements of a basal collection system, e.g., sub-slab aggregate, engineered plenum, pipe specifications
Fan	• Make and model • Maximum wattage, CFM, and pressure • Did site conditions warrant installation of intrinsically safe components? If yes, describe components. • Fan location: exterior, unconditioned attic, other (describe) • Electrical switch installed near fan? Locked? **Note:** The DNR discourages fans from being placed in unoccupied attics and recommends fans to be located exterior to the building where tenants/inspectors have frequent and easy access when practicable and when vandalism is not a reasonable concern.
Exhaust	Minimum distance from doors, windows, chimney flues, and other openings consistent with the design standard used. At buildings where sub-slab concentrations are extremely high (e.g., >100,000 $\mu g/m^3$), outdoor air sampling to verify that there is no impact to air quality from the exhaust of that system.
Monitors and Labelling	• Manometer pressure gauge • Electrical amperage gauge • Telemetry unit • Alarm (visual/audible) • Were labels applied consistent with installation standard? Including labels near manometer, on sump lid, on visible piping on each floor, on electrical panel, and more. • Labels indicate "Soil Gas Control System"? (Note: labeling a soil gas mitigation system installed to address chemical VI as a "Radon Reduction System" is misleading to the occupants, persons responsible for OM&M, and compliance inspectors. If standard company labels include this language, additional labeling should be added to clarify the system is designed to address chemical VI, soil gas or similar.)
Backdraft Testing	Describe if backdraft testing was performed, and if so, was testing done according to the procedures found in section 11.5 of EPA 1993 or a more recent version?

Pressure Field Extension (PFE)	Recommendations:
	• Create and maintain a differential negative pressure of 1 Pa (0.004 inches of water column) at all points where mitigation is necessary.
	• PFE should be measured:
	    o At installation
	    o Second event within 14 to 30 days
	    o Third event during winter assessment period if second event outside winter assessment period
	    o Event during period of high-water table if water table is within five feet of foundation
	• Perform all PFE events during typical building operating conditions (e.g., normal HVAC, entry and exit).
	• Readings from a telemetry unit that has demonstrated to reliably measure PFE may be used in lieu of manual measurements.

<table>
<tr><td></td><td>PFE Conditions:
Did the system achieve a sub-slab vacuum of 1 Pa (0.004 inches of water column) at all points measured?
Was mitigation of the entire foundation performed? If not, describe.
Was PFE measured on opposite sides of interior footings?
Was smoke testing performed?
Were any tests conducted with all combustion appliances and natural draft appliances (e.g., older non-high efficiency furnaces, stove/range hoods, bathroom fans) operating and all windows and doors closed to provide worst case conditions?
Were any events performed on a date when the outdoor temperature was within 10° F of the average annual coldest temperature for the locations?
Were any tests performed when the daytime temperature was above 85° F?
Were the PFE test points abandoned or remain for future use?</td></tr>
<tr><td>Water Table</td><td>If the water table occurs within five feet of the base of the foundation, describe mechanism used to monitor for impact of high-water table.</td></tr>
<tr><td>Documentation</td><td>Physical condition, equipment specifications, and/or operating procedures for each element needed for effective mitigation.
Photograph each design element. This includes elements that will be hidden after construction (e.g., membrane, passive ventilation collection layer, conveyance pipes inside walls) and elements that will remain visible but require future maintenance and monitoring (e.g., suction draw points, manometer, fan, ventilation, foundation as a barrier).
Prepare diagram/map showing location of the design elements (hidden and visible).</td></tr>
<tr><td colspan="2">Baseline Conditions</td></tr>
<tr><td colspan="2">Provide a list of baseline settings for all systems, including:
Pressure differential at all points
Vacuum measured at fan
Acceptable vacuum range (e.g., +/- 20%)
Airflow, if measured</td></tr>
<tr><td colspan="2">OM&M</td></tr>
<tr><td colspan="2">(Wis. Admin. Code §§ NR 724.13(2)(k), (m), and (n))
The OM&M plan must include the following:
Monthly: manometer checks
Annually: Inspect all system parts.
The DNR recommends consideration of the following typical system parts:
Motor for fan/blower is operating.
Suction draw points and sumps remain sealed.
Barrier (foundation) is in similar condition to baseline conditions (compare to photos).
Conveyance pipe vents are clear.
Conveyance pipes are not damaged, cracked, or blocked.
Vacuum probes (if in place for PFE testing) are in good condition and remain capped/sealed.
Test alarm to verify functionality
Telemetry systems components are operable (if applicable).
Contingency: When deviations in operating parameters of more than 20% occur, the DNR recommends a reevaluation of the VMS. These variations may be due to system malfunctions, improper design, changes in the sub-slab environment or changes to the building construction. If the cause of the deviation cannot be determined or repaired, the DNR recommends the system be re-commissioned.</td></tr>
</table>

<table>
<tr><th colspan="2">Chemical Vapor Barriers</th></tr>
<tr><th colspan="2">Design and Commissioning Elements</th></tr>
<tr><td>Design elements and relevant information from the manufacturer</td><td>Membrane Properties (discuss all relevant standards met, e.g., ASTM)
limits vapor transmission of COC (diffusion coefficient)
sufficient thickness, tensile strength and puncture resistance for installation and use (minimum 20-mil thickness, some applications may warrant a thicker membrane)
Description and specifications of other materials used – geotextiles, tapes, etc.
Seams, penetrations, and edges of the membrane are sealed to create a vapor tight condition
Location and sealing of any permanent vapor ports
Installation procedures, including identification and qualifications of installers, oversite provided by the consultant
Quality control procedures including any leak testing performed, compromises discovered, and repairs implemented
Include sketches and photographs showing important design details and construction stages</td></tr>
<tr><th colspan="2">OM&M</th></tr>
<tr><td colspan="2">Include recommendations to replace/repair to original specifications if vapor resistance is compromised.</td></tr>
<tr><th colspan="2">Parking Garages</th></tr>
<tr><th colspan="2">Design and Commissioning Elements</th></tr>
<tr><td>System elements</td><td>Pressure control: Relationship of pressure differential between the parking structure, occupied spaces, and sub-slab.
Ventilation: AER, source of makeup air, capacity of exhaust fans, operational settings (including air sensors, pressure sensors, alarms). Systems that operate continuously rather than on-demand, maintain negative pressure in relation to overlying occupied spaces, achieve minimum air exchanges per hour (for example 0.75 cfm/sf), provide adequate make-up air to minimize negative pressures relative to the sub-surface all increase confidence in the design.
Floor slab: Sealing of foundation slab, cracks, and other penetrations. Upgrading to a chemical vapor barrier will limit VI.
Ceilings: Appropriate sealing of the ceiling above the parking space including any utility penetrations.
Accessory Spaces: All spaces that are adjacent to the ventilated parking structure should be evaluated and mitigated as appropriate. This includes attendant booths, offices, stairwells, and elevator shafts.
Preferential Pathways: Discuss the presence of any preferential pathways (for example block walls, utility penetrations), how they were assessed and sealed to prevent vapors from short-circuiting into occupied spaces.
Include sketches and photographs showing important design details and construction stages.</td></tr>
<tr><th colspan="2">Baseline Conditions</th></tr>
<tr><td colspan="2">Provide a listing of all baseline settings and appropriate operating ranges for all parameters necessary for limiting intrusion of contaminant vapors into occupied structures. This will typically include AER, mechanical system settings (e.g., pressure, concentration detectors), alarm settings, etc.</td></tr>
<tr><th colspan="2">OM&M</th></tr>
<tr><td colspan="2">The OM&M plan should include an appropriate inspection and maintenance frequency for all elements of the design that are necessary for limiting intrusion of contaminant vapors into occupied structures (Wis. Admin. Code § NR 724.13(2)(b)).</td></tr>
</table>

Other Mitigation Strategies
Design, commissioning, baseline, and OM&M building specific. The DNR recommends submitting a workplan with a review fee.

F2.4 Develop an Operation, Monitoring and Maintenance Plan

An OM&M plan is required for a VMS (Wis. Admin. Code §§ NR 708.15(3)(k), NR 724.13(2), NR 724.17(2)). OM&M of the engineered controls that work together to interrupt the vapor pathway is needed to ensure effective mitigation.

Each property has unique building construction and site-specific VMS design; therefore, an OM&M plan is recommended for each VMS on a property (e.g., a multi-family property with five mitigated buildings would have five OM&M plans, one for each building). An OM&M plan consists of the following elements:

- **Baseline Conditions.** A summary of the baseline conditions and performance monitoring results recorded during commissioning. (Wis. Admin. Code § NR 724.13(2)(b), (g))
- **Inspection Plan**. A checklist of system components to inspect and maintenance activities needed for the system to continue to meet performance criteria (Wis. Admin. Code § NR 724.13(2)(b), (e), (k)).
- **Monitoring Schedule.** A monitoring schedule to confirm the system continues functioning (required under Wis. Admin. Code § NR 724.13(2)(d), (k)–(n))

F2.4.1 Timeline

OM&M is required until it can be demonstrated to the DNR that the mitigation system is no longer required (Wis. Admin. Code § NR 724.13(1)(c)), which is usually when the sub-slab vapor concentrations are below VRSLs and/or when any other VRSLs (e.g., groundwater) or VALs in conduit VI are no longer exceeded, as appropriate.

The RP must submit a final OM&M plan with the construction documentation report within 60 days from the date the construction is completed or determined to be essentially complete (Wis. Admin. Code §§ NR 708.15(3)(k), and 724.15(3)(h)). The DNR considers construction to be complete for a VMS when the commissioning is completed, and no further system modifications are needed. If significant time (e.g., one year) passes between completion of commissioning and completion of an OM&M plan it may be appropriate for the system to go through commissioning again to verify performance.

F2.4.2 OM&M Plans with Long-Term Monitoring

The DNR recommends that the OM&M plan is submitted as a separate document; however, it may also be submitted as an appendix to the interim action report/ construction documentation report. Specific report requirements will vary by site depending on contaminant levels, mitigation approach, and land use setting; however, each report should meet the legal requirements of Wis. Admin. Code §§ NR 724.13 and NR 724.17.

User-friendly OM&M Plan
An OM&M plan that can be separated from other reports as a stand-alone document is recommended. User-friendly, stand-alone OM&M plans can be provided to users of each system and attached to each system. This approach may help ensure continued protection of occupants.

The DNR recommends that authors of the OM&M plan keep the end user in mind, often a residential occupant or maintenance person.

Table F-3 summarizes guidelines on the OM&M activities for active depressurization, active indoor air controls, and passive controls. DNR Form 4400-321 provides a fillable OM&M inspection log, primarily for an SSDS, and is available on the DNR's website. This form must be used when applicable (Wis. Admin. Code § NR 727.05(1)(b)3.). The DNR may generate additional inspection logs for other mitigation options. It may be appropriate to develop a site-specific inspection form for complex mitigation systems (e.g., a chemical vapor barrier with sealed elevator pits and modified HVAC controls in a parking garage setting).

The DNR's model OM&M plan may be used as a template for a simple system or incorporated as appropriate when developing OM&M plans for more complex systems. See *Maintenance Plans for Vapor Mitigation Systems/ Vapor Intrusion Response Actions/Vapor Barriers* (RR-981). In general, the DNR recommends including the following in an OM&M plan for a VMS (see Table F-3).

Table F-3. Operation, Monitoring and Maintenance Plan Element Recommendations

Operation, Monitoring and Maintenance Plan Elements	
Design and Commissioning Elements	
General information	• Date of plan • DNR site name and BRRTS # • Property description where mitigation system is located (address, lot, and parcel #). Include specific building letter/number if more than one building on a parcel.
Explanation/ Background	• Why the vapor mitigation system is needed (include type and location of contamination) • Basic description of how the system interrupts the vapor pathway • System diagram with location of all components, including electrical connections, fan(s), suction point(s), piping runs, discharge point(s), active alarm(s), PFE point(s), sump(s), and other components
Baseline conditions	• Initial readings (e.g., PFE testing results, initial manometer reading) • Operating parameters (e.g., flow, pressure). • Physical appearance/condition, using photographs. • Layout (i.e., diagram showing location of elements of system) • Specifications for equipment
Mitigation elements	• Name and description of elements to monitor/inspect/maintain and all system components, including structural integrity. Include photos. • Map or diagram of system components including locations of alarms (and telemetry, as applicable). The DNR recommends a second map or inset of where the mitigation system is located on the property with respect to parcel boundaries, especially for commercial and industrial buildings. • How each element contributes to the mitigation • How often to monitor/inspect/maintain. The DNR recommends inspecting vapor mitigation systems annually by September 30th, prior to the winter heating season. • What to expect to see during an inspection • What to do if test/inspection falls outside of expected conditions • Who to contact if the audible/visual alarm goes off or telemetry indicates that inspection is needed

<table>
<tr><th colspan="2">Operation, Monitoring and Maintenance Plan Elements</th></tr>
<tr><td>Record keeping and communication</td><td>Property owner contact.
Name of contact and company that installed the mitigation system.
Points of contacts for technical questions.
How to contact the DNR.
Contact information for person(s) responsible for OM&M.
Inspection log to record monitoring and maintenance. An explanation of any requirements to maintain the inspection log on site and/or submit the inspection log, as applicable. The DNR recommends submitting vapor mitigation system inspection logs annually by October 15th following an inspection by September 30th. Submittal of inspection logs will likely be required for all sites with CVOCs, either at the time of the interim action report approval or at case closure.
An explanation of any requirements to notify the DNR prior to performing actions that may alter system effectiveness (e.g., building remodeling, addition, plumbing upgrade) (Wis. Admin. Code § NR 724.13(2)(k)). Notification must occur at least 45 days prior to certain actions that are performed after a continuing obligation has been imposed (Wis. Admin. Code § NR 727.07).
Guidelines for recommissioning
Change in land use, building occupancy, or risk criteria.
Substantial changes to the mitigation system (e.g., building remodeling, change in mitigation system fan size, plumbing upgrade).</td></tr>
<tr><th colspan="2">Decommissioning Elements</th></tr>
<tr><td>General Explanation</td><td>Provide a general explanation of decommissioning. Consider the following:
Decommissioning is a process to determine if mitigation will no longer be required by the DNR.
Costs are associated with decommissioning (e.g., sampling, oversight, submittals to the DNR, review fees).
The DNR recommends retaining a qualified mitigation professional.
An environmental consultant should oversee and verify the decommissioning process in accordance with Wis. Admin. Code ch. NR 712.</td></tr>
<tr><td>Decommissioning Guidelines</td><td>Decrease in contaminant concentrations because of remediation or natural attenuation.
Other site-specific criteria.</td></tr>
<tr><td>Decommissioning Process</td><td>Notify the DNR of the decommissioning plan prior to implementation for open cases (Wis. Admin. Code § NR 724.13(4)) or at least 45 days prior to implementing for closed cases (Wis. Admin. Code §§ NR 727.07(4) and NR 727.09) and submit associated fees (Wis. Admin. Code § NR 727.11 and ch. NR 749).
Collect data that supports guidelines for decommissioning the mitigation system.
Request DNR approval to remove the vapor mitigation system and/or the related continuing obligation requirements from the property. Generally, this request is made through an application for a continuing obligation modification with appropriate fees (Wis. Admin. Code § NR 727.09 and ch. NR 749).</td></tr>
<tr><th colspan="2">Optional</th></tr>
<tr><td colspan="2">Include information about how a VMS can also be used to prevent intrusion of radon gas, so its continued operation may be beneficial, even after the system is no longer required for chemical VI.</td></tr>
</table>

F2.5 Perform OM&M until No Longer Required by the DNR

F2.5.1 Stewardship Monitoring

Stewardship monitoring includes OM&M following commissioning to verify continued system performance. At a minimum, the following actions are required (Wis. Admin. Code § NR 724.13):

- Monthly manometer checks (Wis. Admin. Code § NR 724.13(2)(m)) (usually conducted by the occupant);
- Annual inspection of all system parts (Wis. Admin. Code § NR 724.13(2)(n)), with emphasis on moving parts such as a fan; and
- Any system-specific instructions as defined in the OM&M plan (Wis. Admin. Code § NR 724.13(2)(e), (k)).

The DNR recommends inspecting vapor mitigation systems annually by September 30th, prior to the winter heating season. The DNR also recommends submitting VMS inspection logs annually by October 15th following the inspection (if required to submit). The DNR is likely to require annual submittal of inspection logs for all sites with CVOCs, either upon interim action report approval or at case closure. (Wis. Admin. Code § NR 727.05(1)(b)3.)).

Notification to the DNR is required in advance of any planned events that may compromise the integrity of the mitigation system and diminish its protection from VI (Wis. Admin. Code §§ NR 724.13(2)(k) and NR 727.07(4)). Notify the DNR project manager as soon as practicable following unplanned events (e.g., flooding). To meet case closure criteria, the VMS may need to be recommissioned to verify a VAL is not likely to be attained or exceeded (Wis. Admin. Code §§ NR 726.05(4)(a), (e) and (8)(b)2.). When necessary, modifications to the system must be documented, and the OM&M plan updated (Wis. Admin. Code §§ NR 724.13(4) and NR 724.15(3)(h)). The DNR recommends that recommissioning occur within four to eight weeks, or within two weeks if an acute health risk may be present. See Table 2 for recommended timeframes.

The following events may compromise the integrity of a VMS and diminish its protection from VI:

- A new addition is constructed or significant renovation occurs that changes the building layout, occupancy or use
- Heating or cooling systems are significantly altered resulting in changes to air pressures or distribution
- Ventilation is significantly altered by extensive weatherization or changes to mechanical systems
- Significant openings to soil occur due to either changes in water control systems (e.g., sumps, drain tiles), or natural settlement, causing major cracks to develop
- Earthquakes, blasting, flooding, or formation of sink holes nearby
- An installed mitigation system is altered or repaired, not including fan replacement with a similar fan

F2.6 Decommissioning the System

F2.6.1 Active Mitigation System (SSDS, SMDS, SSVS)

Any mitigation system with a fan or blower that creates positive or negative pressure beneath the foundation slab can affect concentrations of sub-slab vapors. Samples collected during system operation may not be representative of sub-slab vapors during times when the system is turned off. If the system is shut off, contaminant concentrations in indoor air may quickly rebound to pre-mitigation levels and create a health risk to occupants. The risk is greatest if either TCE is the COC, or concentrations of any contaminant exceeded acute health risk concentrations in either indoor air or sub-slab vapors prior to mitigation. Samples collected during operation may not accurately reflect shut-down conditions; however, sample results can help indicate the value of turning off the system to perform additional decommissioning steps. Table F-4 includes recommendations for decommissioning an active mitigation system.

Table F-4. Decommissioning Recommendations for Active Mitigation Systems

<table>
<tr><th>Decommissioning Recommendations for Active Mitigation Systems</th></tr>
<tr><td>Scenario A applies if:
1. TCE is a COC, or
2. At the time of the investigation, other COC concentrations at the building of concern were either:
a. a carcinogen for inhalation toxicity was above 10 times the VRSL, or
b. a non-carcinogen for inhalation toxicity was above three times the VRSL.</td></tr>
<tr><td>• Notify the DNR and obtain approval in advance of initiating work.
• Prior to shutting off the system, collect longer-duration samples from representative sub-slab vapor locations and from each exhaust riser for the VMS and analyze for the COCs found during the site investigation. Consider the site investigation results and all LOEs for the site when determining the number of sub-slab vapor sampling locations.
• If any result is above a VRSL, decommissioning is not recommended, and OM&M should continue.[a]
• If all results are below the VRSLs, deactivate the system and sample at the intervals described below.
o Sub-slab Vapor. Collect at least three rounds of sub-slab vapor samples from each probe sampled above, during the following periods after system deactivation:
▪ Between two to four weeks, paired with indoor air as described below;
▪ Between two to six months; and
▪ Between nine months to one year.
▪ At least two of these events should be longer duration sampling events (see Section 8.5.3) during the winter assessment period,[b] with at least one event paired with indoor air as described below.
▪ Additional sampling events may be needed based on site-specific circumstances such as the distance of the building from the source, the type of contaminants, the residual contaminant concentrations, etc.
o Indoor Air. Collect indoor air samples within the following time periods:
▪ Between two to four weeks after shutting down, collect 8-hour duration samples for worker settings or 24-hour duration samples for residential settings with a normal lab turnaround; and
▪ A long-duration sample collected during the winter assessment period.
• If either the indoor air concentration exceeds the VAL absent a verified indoor air source, or a sub-slab vapor concentration exceeds a VRSL, immediately restart the system and return to OM&M [a].</td></tr>
<tr><td>Scenario B applies to all situations that do not meet Scenario A above.</td></tr>
<tr><td>• Notify the DNR and obtain approval in advance of initiating work.
• For Sub-slab Vapor - Collect samples from representative sub-slab locations and analyze them for the COCs found during the investigation. Consider the investigation results and all LOEs for the site when determining the number of sub-slab vapor sampling locations. At minimum, collect samples during the following periods after system deactivation:
o Between two to four weeks;
o Between two to six months; and</td></tr>
</table>

- o Between nine months to one year.
- o At least two of the events listed above should be collected during the winter assessment period, with at least one event paired with indoor air as described below.
- o Additional sampling events may be needed based on site-specific circumstances such as the distance of the building from the source, the type of contaminants, the residual contaminant concentrations, etc. Some long-duration samples will provide greater confidence that concentrations have been adequately characterized.
- *For Indoor Air*. Collect a long duration sample during the winter assessment period.
- If either the indoor air concentration exceeds the VAL absent a verified indoor air source, or a sub-slab vapor concentration exceeds a VRSL, immediately restart the system and return to long-term OM&M [a].

Notes:

a. The amount of time to wait to restart the decommissioning process will depend on circumstances and concentrations detected in vapor samples.

b. **The winter assessment period is December 1 to March 31.** In lower-risk situations when one sampling event during the winter assessment period is recommended, collect samples any time during the winter assessment period. In higher-risk situations when multiple rounds of sampling are recommended, conduct the initial round as early as possible during the winter assessment period and additional sample rounds later in the season (see also Table 2, Note d). Sampling during different portions of the season may build confidence in indoor air quality results. If the site investigation indicated that the highest vapor concentrations occurred outside the winter assessment period, the DNR recommends additional sampling that focuses on the conditions that caused the results to be higher. The higher concentrations outside of the winter assessment period may be related to building operation, water table conditions, meteorological factors or other site-specific factors.

F2.6.2 All Other Systems

Passive Sub-slab or Active Indoor Air Controls: Passive sub-slab systems and/or active indoor air controls are mitigation systems that do not have a fan or blower that creates negative or positive sub-slab pressure and potentially affects sub-slab vapor concentrations. To decommission buildings with these systems, complete a sub-slab vapor investigation consistent with the recommendations in Section 8. If any result exceeds a VRSL, the DNR recommends ceasing the decommissioning process and continuing OM&M. The amount of time to wait to restart the decommissioning process depends on circumstances and concentrations detected in vapor samples.

Conduit Mitigation: Conduit mitigation includes any system installed to prevent contaminant vapors from entering the occupied space directly through conduits. Decommissioning typically involves the steps below.

1. Document that vapor concentrations in conduits are no longer above a concentration that would cause exceedance of a VAL if the system were to shut down. Verify the absence of any acute risk, especially if TCE was a COC or concentrations in the conduit during the investigation were above three times the VAL for a non-carcinogen or above ten times the VAL for a carcinogen. See RR-649, *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors*, for additional details and considerations.
2. Deactivate any active elements of the system, such as a blower for a conduit ventilation system.
3. Monitor conduit and indoor air concentrations for a period. In most cases, this step should include sampling indoor air within two to four weeks with sampling repeated at approximately 90 and 180 days.

Mitigation and decommissioning strategies of conduits are building specific.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix G – Deliverables for Vapor Intrusion

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

The table below summarizes deliverables required or recommended when evaluating the vapor pathway under Wis. Admin. Code chs. NR 700 - 799. Additional information or deliverables may be required or recommended to evaluate other pathways or site conditions.

ITEM	WIS. ADMIN. CODE	SUMMARY
Site Investigation (SI) Scoping and Work Plan	§ NR 716.07 § NR 716.09	• Submit the SI work plan to the DNR within 60 days from notification that a site investigation is required (e.g., RP letter). • Use vapor screening (Section 2) to help with the SI scoping and work plan (Section 5). • Include a summary of the results of vapor screening to either support the SI work plan or justify why a vapor investigation is not needed.
Notification to the public and affected parties	§ NR 714.07	• Evaluate the need for notification and public input; the need and approaches may vary based on site-specific circumstances. Notifications may be required to affected parties and the public (e.g., when there is a high level of concern for public health and safety). • Provide the DNR with copies of letters and a summary of other communications as needed to document best efforts to gain access (Section 4).
Notification of Sampling Results	§ NR 716.14	• Provide a copy of vapor sampling data to the DNR, property owners and occupants (as applicable) within 10 business days from receiving the sample results (unless a different notification schedule was approved by the DNR). • Provide all results and a preliminary analysis of the cause of any significant detections. Transmittals of sampling results and other specified information must be provided in a letter or on a DNR form to property owners and occupants, as applicable (Wis. Admin. Code § NR 716.14(2)(c)).

<table>
<tr><th>ITEM</th><th>WIS. ADMIN. CODE</th><th>SUMMARY</th></tr>
<tr><td>Immediate or Interim Action Plans and Reports (i.e., Vapor Mitigation)</td><td>§ NR 708.05

§ NR 708.11

ch. NR 724</td><td>Evaluate the need for immediate or interim action to mitigate exposure to vapors during the site investigation (Section 2.2). Documentation is required as described below.
Immediate action: Provide documentation of any immediate actions taken, including to mitigate exposure to vapors, within 45 days after notification of the discharge.
Interim action: Provide the DNR with design and implementation plans for the interim action selected to mitigate exposure to vapors, when applicable in accordance with Wis. Admin. Code § NR 708.11(4); include construction documentation in the construction documentation report (see Wis. Admin. Code ch. NR 724 requirements, including those specified below).
For vapor mitigation, construction documentation follows the commissioning phase. Construction is considered complete after commissioning is complete and performance is verified (see Appendix F, Section F2.3). Continuing obligations associated with the system may be imposed at the time of its approval (Wis. Stat. § 292.12(2)).</td></tr>
<tr><td>Site Investigation Report</td><td>§ NR 716.15</td><td>Summarize the vapor investigation results and conclusions in the SI report within 60 days of completing the field investigation and receiving all laboratory data. Use the analysis to justify the scope of the vapor investigation or explain why a vapor investigation was not needed (Section 2.1).
Methods: Describe the sampling and quality control methods (Section 8.2).
Tables: Compile all sampling results in data tables that identify the sample location and compare results to appropriate risk screening levels (Section 9).
Maps: Show all sampling locations and results on site maps and identify sample locations where the results were over risk screening levels. Distinguish between soil gas, sub-slab, indoor air or other types of samples.
Cross-Sections: Include sampling results in cross-sections with site stratigraphy and water levels; the depth of vapor samples and the elevation of the building foundation may assist with the interpretation of sampling results.
Photographs: Include photographs to show the site conditions at sampling locations (e.g., a well-maintained and large-space industrial building versus a run-down building with small interior spaces and foundation cracks).
Interpretation: Use the geology, preferential pathways, building location and contaminant distribution to evaluate the vapor sampling results and evaluate whether the extent of vapor impacts was delineated.</td></tr>
</table>

ITEM	WIS. ADMIN. CODE	SUMMARY
Remedial Action Options Report	§ NR 722.09 § NR 722.13	Submit a remedial actions option report to the DNR within 60 days of the site investigation report. Consider the vapor pathway(s) when selecting a remedial action for a site. The DNR may require vapor control technologies (e.g., air scrubber on an SVE) as a condition of approving the remedial action (Wis. Admin. Code § NR 722.15(2)(e)(4)-(5)). **Note:** In general, vapor mitigation is an interim action and is not equivalent to remediation. Remedial actions are implemented to reduce the mass and concentration of the source of vapors. The law requires that a remedial action is conducted that reduces the mass and concentration of volatile compounds before case closure may be approved, if vapor concentrations met or exceeded VRSLs (Wis. Admin. Code § NR 726.05(8)(b)).
Design Report, Plans and Specifications for Remedial Actions	§ NR 724.09 § NR 724.11	Provide design plans and specifications to the DNR for each remedial action (and each interim action specified under Wis. Admin. Code § NR 724.02(1)) selected for a site. • *Schedule:* Tell the DNR the proposed dates for starting and completing the work. • *Performance Verification Plan:* Include a preliminary plan for the method of demonstrating that the design meets performance criteria. • *OM&M Plan:* Provide preliminary discussion of planned operation, monitoring and maintenance.
Construction Documentation Reports for Remedial Actions	§ NR 724.15	Provide a documentation report to the DNR for any remedial action (or interim action specified in Wis. Admin. Code § NR 724.02(1) (e.g., vapor mitigation)) within 60 days after completing construction. • *Performance Verification:* Document that the final action meets design criteria. • *As Built Conditions:* Document the baseline conditions that meet the design criteria. For vapor mitigation, construction documentation follows the commissioning phase. Construction is considered complete after commissioning is complete and performance is verified (see Appendix F, Section F2.3).

ITEM	WIS. ADMIN. CODE	SUMMARY
OM&M Plans for Interim and Remedial Actions	§ NR 708.11(4) § NR 724.13 § NR 724.17	Submit the OM&M report to the DNR if OM&M is needed to ensure the effectiveness of a remedial or interim action (see Appendix F, Section F2.4). For a OM&M plan addressing vapor mitigation, it is recommended that the OM&M plan: • Includes specific information for *each system* installed. • Is submitted *after commissioning* is complete and no further changes to the system are needed. • Is submitted as a stand-alone document (i.e., appendix) that is not embedded within the narrative of the Construction Documentation Report (so that it can be separated out, readily available on site/tied to the system and referenced by the user). • Is prepared by the RP; however, implementation may become the *responsibility of the property owner* after case closure, and the DNR recommends that the OM&M plan is prepared with this in mind (e.g., use plain language, include diagrams).
Notification of Continuing Obligations	§ NR 725.05 § NR 726.11 § NR 726.13	At least 30 days prior to submitting a case for closure, notify property owners (and occupants as appropriate) that they will become responsible for maintaining the vapor mitigation system, and any other continuing obligations for which they will be responsible to ensure continued protection from exposure to vapors (see Section 4 and Table 1). • Provide owner/occupants with a copy of the OM&M plan. • Provide the DNR a copy of the notification and certification of receipt of the notice (Wis. Admin. Code §§ NR 726.05(2), 726.09(3)) • It is recommended that the DNR is provided a copy of any legal agreement made between the RP and property owner(s) or others that obligates a party to maintain a continuing obligation. At the time vapor mitigation is installed on an off-site property, the DNR recommends the RP informs the property owner that they may become responsible for operating the mitigation system when the case is approved for closure. The DNR recommends RPs follow the same notification process when continuing obligations are anticipated to be imposed at the time of approval of interim actions.

ITEM	WIS. ADMIN. CODE	SUMMARY
Closure	§ NR 726.05 § NR 726.05(8) § NR 726.09	If requesting case closure, provide the DNR with the data and evaluation that demonstrates that exposure to VI is currently prevented, and site conditions will remain protective in the future. • *Screening*: Summarize information used in the vapor screening. Justify the scope of the vapor investigation or explain why vapor sampling was not needed. • *Data:* Summarize all the vapor sampling results (*e.g.*, site investigation, post-remediation, and performance verification), and compare to appropriate vapor screening levels. • *Interim or Immediate Actions*: Describe and depict where interim or immediate actions were completed to mitigate exposure from VI. Include performance verification that documents effectiveness. • *Remedial Action:* Summarize the remedial actions taken to reduce the mass and concentration of the vapor source or provide justification for no remedial action. • *Long-term OM&M for Vapor Mitigation:* Provide the DNR a copy of an OM&M plan for each mitigation system (or an updated OM&M plan, as appropriate). In the OM&M plan, include any information needed to keep the system functioning in a way that meets or exceeds design criteria. • *Continuing Obligations:* List and depict the properties for which a continuing obligation may be required by the DNR for continued protection from exposure to vapors.

Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix H – Letters from the Wisconsin Department of Health Services

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

The following letters from the Wisconsin Department of Health Services (DHS) to the DNR are included:

1. December 7, 2017 – DHS response to Request for Opinion on risk guidelines in DNR's Vapor Intrusion Guidance RR800; comments to immediate action criteria and trichloroethylene (TCE) acute risk
2. March 25, 2021 – DHS response to Request for Assistance: Actions for Trichloroethylene at Acute Risk Levels
3. June 6, 2022 – DHS response to Request for Assistance: Clarification of single exposure for trichloroethylene (TCE)

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December 7, 2017

Darsi Foss
Director, Remediation and Redevelopment Program
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Subject: DHS response to Request for Opinion on risk guidelines in DNR's Vapor Intrusion Guidance RR800; comments to immediate action criteria and Trichloroethylene (TCE) acute risk.

Dear Ms. Foss:

In your October 26, 2017 letter, you asked for a formal response from the Department of Health Services (DHS) to two areas of comments received on the Wisconsin Department of Natural Resources (DNR) draft revision to RR800 – Addressing Vapor Intrusion at Remediation and Redevelopment Sites in Wisconsin:

1. Immediate action criteria. *Please review the guidelines for immediate action in RR800, and provide written opinion of the DNR's proposed immediate action guidelines (sec. 7.1, RR800 draft).*
2. Trichloroethylene (TCE) Acute Risk. *Please review the ACC's September 8, 2017 letter to DNR under the heading "DNR should not adopt a policy for TCE remediation based on potential acute (short-term) risks," and provide written opinion if there is sufficient weight of scientific evidence to continue with more urgent/immediate response when TCE is the contaminant of concern and women of childbearing age are present.*

DHS response:

***Immediate Action Criteria*: DHS concurs with DNR's proposed immediate action guidelines.**

The central feature of the immediate action criteria allows for immediate intervention if:

- indoor air concentrations are over 10 times the Vapor Action Limit (VAL) for carcinogens or,
- indoor air concentrations are over 3 times the VAL, for non-carcinogens

These immediate action guidelines are consistent with EPA guidance for a Category 4 – High priority removal site.[1] They are also consistent with the EPA *Regional Removal management Levels Users Guide,* [2] which includes supporting RML tables that use a 10^{-4} risk level for carcinogens (equivalent to 10-fold over the 10^{-5} target risk level for the VAL) and an HQ (hazard quotient) of 3 for noncarcinogens (3-fold over the VAL). There is a mechanistic basis for using differing concentration magnitudes over the Vapor Action Limits with regard to acute exposures to carcinogens versus non-carcinogens. The EPA has noted there is a reasonable assumption that non-carcinogenic effects result from acute to subacute exposures, and plausibly from a single exposure: "In most cases, it is assumed that a single exposure at any of several developmental stages may be sufficient to produce an adverse developmental effect, but the RfC for a single exposure hasn't been determined yet by EPA."[3] For these reasons DHS agrees with the precaution of using DNR's proposed immediate action criteria. As noted, these would be 3 times the VAL for non-carcinogenic (including developmental) effects, and 10 times the VAL for carcinogenic effects, where the probability of genotoxic carcinogenesis is calculated on the basis of exposures over long exposure durations at low concentrations not expected to cause acute effects.

***TCE Acute Risk:* DHS recommends urgent/immediate response when TCE is the contaminant of concern and women of childbearing age are present.**

In a September 8, 2017 letter to DNR, one commenter, the American Chemistry Council (ACC), disagrees with using the acute risk of fetal heart malformation as basis for decisions for sites with TCE contamination because of controversy over the risk assessments. There is a substantial body of literature on the toxicological effects of TCE that considers both cancer and non-cancer endpoints, including the effects of TCE on fetal heart development in rodent and avian models (for more information, see reviews by the U.S. Environmental Protection Agency[4] and the Agency for Toxic Substances and Disease Registry[5]). This literature will be more complete with better demonstrations of congenital fetal heart defects through the inhalation route. There are uncertainties in the use of animal models, such as subtle differences in the developmental windows of rats, chickens, and humans; species-level metabolism; and metabolic differences in oral exposure vs respiratory exposure (*i.e.,* uptake rates and tissue-specific enzyme expression). Any of these could confound the extrapolation of a relevant drinking water dose to a comparable respiratory dose calculated solely on the basis of ventilation rates. Nonetheless, based upon

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[1] EPA. 2010. Vapor Intrusion Guidebook. United States Environmental Protection Agency. Internet https://www.epaosc.org/sites/3806/files/VI%20Guidebook%20-%20%2010-1-10%20-%20final%20version.pdf.

[2] EPA. 2017. Regional Removal Management Levels for Chemicals (RMLs). United States Environmental Protection Agency. Internet https://www.epa.gov/risk/regional-removal-management-levels-chemicals-rmls

[3] Richardson, RH. Aug 27 2014. EPA Memo from Office of Superfund Remediation and Technology Innovation: *Compilation of Information Relating to Early/Interim Actions at Superfund Sites and the TCE IRIS Assessment.*

[4] EPA. 2011. Toxicological Review of Trichloroethylene. United States Environmental Protection Agency, Integrated Risk Information System. EPA/635/R-09/011F. Internet https://www.epa.gov/iris/supporting-documents-trichloroethylene

[5] ATSDR. 2014. Toxicological profile for Trichloroethylene (TCE) (Draft for Public Comment). Agency for Toxic Substances and Disease Registry (ATSDR). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Internet https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=173&tid=30.

available evidence, we cannot exclude the relationship between TCE exposure and heart defects, and recommend a precautionary approach to continue with a more urgent and immediate response when TCE is the contaminant of concern and women of childbearing age are present.

Of note, we reviewed the reviewed the California Office of Environmental Health Hazard Assessment (OEHHA) document showcased in the argument by the ACC. The ACC provides a long quote from OEHHA,[6] presenting this as the basis of OEHHA decision to "reject the findings" of TCE-related fetal heart malformations. We disagree with this characterization. In our review of this 2009 document, it appears that OEHHA thoroughly reviews the TCE/heart malformation literature, noting both strengths and shortcomings of this research, but the 2009 document does not present an independent conclusion or policy recommendation based on this review. Later, in a 2013 OEHHE *Request for Information,*[7] OEHHA clearly states their determination that *"TCE appears to meet the criteria for listing as known to the State to cause reproductive toxicity under Proposition 65, based on findings of the U.S. EPA ...."* This reference goes on to detail their determination, on the basis of male reproductive toxicity and developmental toxicity:

> "The critical effects identified as the basis for the chronic oral reference dose (RfC) in the TCE IRIS entry (U.S. EPA, 2011a) and the Toxicological Review (U.S. EPA, 2011b) include developmental toxicity manifested as increased fetal cardiac malformations in rats and developmental immunotoxicity in mice following prenatal exposure. This appears to meet the criterion in Section 25306(d)(1) that the chemical "has otherwise been identified as causing ...reproductive toxicity by the authoritative body in a document that indicates that such identification is a final action".

We refer you to these OEHHA documents for more information. It should be noted that California's review is focused on drinking water, not indoor air. With regard to ACC's reference to conclusions made by the Indiana Department of Environmental Management (IDEM), ACC quotes a one-page memo from IDEM that concludes "an accelerated response [to TCE and fetal cardiac malformations] is not scientifically supportable based upon current information." Although the ACC accurately quotes the memo, the memo provides no details or references supporting IDEM's conclusion. Several other states, including Alaska, Massachusetts, New Jersey, Connecticut, Minnesota, and New Hampshire have revised their TCE action levels in response to the EPA assessment (reviewed by Clapp et al.[8]). We have not examined these other

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[6] OEHHA. 2009. Public Health Goals for Chemicals in Drinking Water: Trichlorothylene. California Office of Environmental Health Hazard Assessment. Internet https://oehha.ca.gov/media/downloads/water/chemicals/phg/tcephg070909_0.pdf

[7] OEHHA. 2013. Request for Relevant Information: Trichloroethylene (TCE). California Office of Environmental Health Hazard Assessment. Internet https://oehha.ca.gov/proposition-65/crnr/request-relevant-information-trichloroethylene-tce.

[8] Clapp B, Frost DJ, Kray SE. 2016. Environmental Law News (25)31-39. Internet https://files.skadden.com/sites%2Fdefault%2Ffiles%2Fpublications%2FThe_Evolving_Regulation_of_TCE_Vapor_Intrusion_Issues.pdf.

state's revisions in detail, but are aware that the Wisconsin DNR regularly discusses these topics with other U.S. EPA Region 5 states. DHS is available to participate in discussions with other states as needed.

Thank you for the opportunity to comment on this topic. For further discussion, please contact Robert Thiboldeaux, robert.thiboldeaux@wi.gov, 608-267-6844.

Sincerely,

Jeffrey Phillips
Acting Director, Bureau of Environmental and Occupational Health

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March 25, 2021

Christine Haag
Program Director
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Subject: DHS response to Request for Assistance: Actions for Trichloroethylene at Acute Risk Levels

Dear Ms. Haag:

The Wisconsin Department of Health Services (DHS) received your letter dated October 18, 2019 requesting clarification on the definition of acute risk and timeline justifications for responding to various scenarios where the acute risk is related to volatile organic compounds (VOCs) and vapor intrusion (VI).

This request for clarification is intended to augment a December 7, 2017 DHS letter to the Wisconsin Department of Natural Resources (DNR) providing recommendations for when immediate action is needed in response to written comments on proposed revisions to the RR-800 document. Specifically, DHS concurred with DNR's position that immediate action is justified when indoor air is found to be present at three (3) times the indoor air vapor action level (VAL) or sub-slab vapor risk screening level (VRSL) for a non-carcinogen or ten (10) times the VAL or VRSL for a carcinogen. In addition, DHS supported the DNR's position that immediate action be taken when trichloroethylene (TCE) is present in indoor air above the VAL and when women of child-bearing age are present.

DHS response:

DHS clarification statements defining acute risk and justifying timelines for responding to acute risk follow for each of the DNR scenarios presented in the request letter:

1. **Clarification from DHS that acute risk necessitates immediate action as defined in s. NR 700.03(28), Wis. Admin. Code.**

   To reinforce the finding in the December 7, 2017 letter, DHS is in agreement that DNR's immediate action as defined in s. NR 700.03(28), Wis. Admin. Code is warranted when acute risk is observed as discussed in DNR's Vapor Intrusion Guidance RR800 (2018). For all contaminants with the exception of trichloroethylene (TCE) when women of childbearing years (age 15 to 44) are present, acute risk is defined as indoor air concentrations that are three times over the vapor action limit (VAL) for non-carcinogens or ten times over the VAL for carcinogens. For TCE where people who are or may become pregnant occupy a dwelling, acute risk is defined as indoor air concentrations that are equal to or over the VAL (HI $\geq$ 1). These immediate action guidelines are in agreement with EPA guidance. The following statement is from the EPA OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (EPA 2015): "Although the indoor air concentrations may vary temporally, an appropriate exposure concentration estimate (e.g., time-integrated or time-averaged indoor air concentration measurement in an occupied space) that exceeds the health-protective concentration levels for acute or short-term exposure (i.e., generally considered to be a hazard quotient (HQ) greater than one for an acute or short-term exposure period) indicates vapor concentrations that are generally considered to pose an unacceptable human health risk."

2. **Clarification from DHS that trichloroethylene (TCE) present in indoor air above the applicable VAL qualifies as an acute risk to women of child-bearing years.**

DNR basis its VAL and VRSL values on EPA regional screening levels (RSLs) for indoor air. These values are developed using reference concentrations (RfCs) from EPA's toxicological assessments developed for its Integrated Risk Information System (IRIS). The non-cancer chronic inhalation RfC of $2x10^{-3}$ mg/m^3 in EPAs toxicological assessment for TCE (2011) is based upon two rodent drinking water exposure studies. One study (Kiel et al., 2009) reported an immunotoxic effect of TCE presenting as a reduced thymus weight in female mice. The other study reported an increased incidence of fetal cardiac malformations (Johnson et al., 2003). The cardiac malformation developmental endpoint drives the concern over short term exposure to TCE. Although some limitations were reported with the Johnson et al. study (2003), the cardiac malformations finding has been confirmed by several reviews since, including the EPA Office of Solid Waste and Emergency Response (2014), ATSDR (2014), the Massachusetts Department of Environmental Protection (MADEP, 2014), a group of EPA researchers (Makris et al, 2016), and the North Carolina Department of Environmental Quality (NC DEQ, 2018). These reviews found that a two- to three-fold increase in congenital heart defects were observed in multiple animal studies and that the most frequently observed heart defects were also reported in humans exposed to TCE-containing VOCs in several epidemiological studies (Brender et al. 2014, Dawson et al. 1993). These reviews also found that mechanistic support exists with studies in avian and mammalian cells demonstrating that TCE exposure alters processes that are critical to normal valve and septum formation. Although a recent EPA TSCA Risk Evaluation for TCE (2019) used the immunotoxic end point and not the fetal cardiac malformation end point for their risk determinations, the EPA Science Advisory Committee on Chemicals (SACC) was split on whether to use the fetal heart malformations endpoint for risk consideration and the TSCA Risk Evaluation was not allowed to consider epidemiological evidence or the effects of TCE exposure from air, contaminated waste sites, groundwater used for drinking water, and food in their evaluation.

The EPA identifies that a single exposure at any of several developmental stages may be sufficient to produce an adverse developmental effect (EPA, 1991). In humans, the cardiac system is the second to develop following fertilization, with cardiac development beginning at approximately 3 weeks following implantation. Substantial cardiac system development continues through 8 to 9 weeks post implantation, with the most sensitive period of cardiac development occurring in 3 to 6 weeks (Smart and Hodgson, 2018). These critical fetal heart development windows occur during a time period when an individual may not yet know they are pregnant. Rapid actions should be taken to minimize the potential for TCE exposures during these timeframes (EPA 2014, EPA Region V, 2020).

3. **Health-based recommended responses including the definition of critical exposure windows with scientific justification to help inform DNR determination of time lines for immediate (s. NR 700.03(28), Wis. Admin. Code) and interim (s. NR 700.03(29), Wis. Admin. Code) actions in the following scenarios:**

    a. **TCE is present beyond the envelope of a building at or above the applicable Vapor Risk Screening Level (VRSL);**

    DHS recommends an evaluation of the demographics for the building. If persons of childbearing years occupy the dwelling, indoor air samples should have a quick turnaround time (24 to 72 hours, EPA Region 9, 2014). Women in the sensitive demographic should be consulted about the potential TCE developmental toxicity risk so they may make informed decisions in terms of staying in the dwelling during the timeframe of the indoor air assessment. DHS or local health can assist with this consultation. If the indoor air TCE sample result exceeds the VAL, DHS recommends interim action (carbon filter unit) and rapid installation of sub-slab depressurization system within two weeks. If the indoor air TCE sample result is less than the VAL, mitigate and monitor indoor air in interim to ensure exposure is not occurring and move toward installation of a mitigation system within 4 to 8 weeks, depending upon the building's complexity and need for system design.

    b. **Non-carcinogenic compounds are present beyond the envelope of a building at or above three (3) times the applicable VRSL;**

    The U.S. EPA defines a reference concentration (RfC) as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure of a chemical to the human population through inhalation (including sensitive subpopulations), that is likely to be without an appreciable risk of deleterious effects during a lifetime (IRIS Glossary, 2020). When a non-carcinogenic VOC is three times above the applicable VRSL, the risk of that VOC being present in indoor air at levels that can cause an adverse health effect is high enough to warrant urgent action including indoor air sampling with 24 to 72 hour turnaround time and mitigation within 4 to 8 weeks, or sooner where indoor air sampling results indicates a VAL exceedance.

c. **Carcinogenic compounds are present beyond the envelope of a building at or above ten (10) times the applicable VRSL;**

VRSLs are established in Wisconsin with a 10^{-5} cancer risk. When a carcinogenic compound is present in indoor air at or above ten times the applicable VRSL, the cancer risk exceeds 10^{-4} cancer risk. The risk of cancer occurrences from continuous exposure is therefore high enough to warrant the installation of a mitigation system within 4 to 8 weeks, depending upon the building's complexity and need for system design.

d. **TCE is present in indoor air below the applicable VAL**

Review sub-slab results when available. If sub-slab TCE data is also below VRSL, additional assessment should take place with normal laboratory turnaround time to confirm results are below action levels. If women of childbearing years occupy the building, an additional sampling round should take place as soon as feasible to ensure levels above VAL/VRSL is not present.

e. **Non-carcinogenic compounds are present in indoor air between the applicable VAL and three (3) times the applicable VAL;**

Move toward mitigation system installation within 4 to 8 weeks, depending upon complexity and need for system design. Perform indoor air sampling to confirm mitigation system is effective.

f. **Carcinogenic compounds are present in indoor air between the applicable VAL and ten (10) times the applicable VAL;**

Move toward mitigation with a recommended timeframe of 4 to 8 weeks, depending upon complexity and need for system design. Perform indoor air sampling to confirm mitigation system is effective.

g. **TCE is present in indoor air at or above the applicable VAL;**

DHS recommends an evaluation of the demographics for the building. If women of childbearing years occupy the building, implement interim actions such as carbon filtration units to interrupt the TCE exposure. Move toward installation of a mitigation system within two weeks. Women in the sensitive demographic should be consulted about the potential TCE developmental toxicity risk so they may make informed decisions in terms of staying in the dwelling during the timeframe of the indoor air assessment.

h. **Non-carcinogenic compounds are present in indoor air at or above three (3) times the applicable VAL;**

The U.S. EPA defines a reference concentration (RfC) as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure of a chemical to the human population through inhalation (including sensitive subpopulations), that is likely to be without an appreciable risk of deleterious effects during a lifetime (IRIS Glossary, 2020). When a non-carcinogenic VOC is three times above the applicable VAL, the risk of adverse health effects occurring from continuous exposure is high enough to warrant the installation of a mitigation system within 4 to 8 weeks, depending upon the building's complexity and need for system design. Depending upon how far above the VAL the concentration is, more urgent actions may be needed, and the local health officer should be consulted for potential abatement orders, placarding, and temporary relocation of occupants per Section 254 Wis. Admin. Code.

i. **Carcinogenic compounds are present in indoor air at or above ten (10) times the applicable VAL.**

When a carcinogenic compound is present in indoor air at or above ten times the applicable VAL, the cancer risk exceeds 10^{-4} cancer risk. The risk of cancer occurrences from continuous exposure is therefore high enough to warrant the installation of a mitigation system within 4 to 8 weeks, depending upon the building's complexity and need for system design. Depending upon how far above the VAL the concentration is, more urgent actions may be needed, and the local health officer should be consulted for potential abatement orders, placarding, and temporary relocation of occupants per Section 254 Wis. Admin. Code.

4. **Health-based recommendations for when sampling indoor air at commercial or industrial businesses is necessary in light of the recent Department of Defense study on sewers and utility tunnels as preferential pathways (*Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors And Investigation Protocol*, ESTCP Project ER-201505).**

DHS agrees with the finding in the DoD study that indoor air should be part of the VI assessment where evidence of preferential pathways might be feasible. This evidence may include detection of VOCs in sewer lines or utility corridors. Recent experience has shown instances where indoor air levels are found at high levels due to preferential pathway contamination through open sumps, openings in foundations, and poorly sealed conduits. DHS also recommends sampling indoor air when environmental sampling (groundwater, soil, or soil gas) indicates that indoor air action levels could be exceeded. When TCE is the contaminant of concern, indoor air should always be evaluated to assist with the risk assessment and be able to interrupt exposures as soon as possible to sensitive populations to prevent the known reproductive/developmental endpoint. When commercial or industrial businesses are users of the VOCs being studied, those chemicals may need to be temporarily removed prior to the indoor air assessment, where feasible.

Thank you for the opportunity to provide feedback on this topic. Please contact me at (608) 266-6677, or curtis.hedman@wisconsin.gov if you have any follow up questions or comments about this response.

Sincerely,

Curtis Hedman, Ph.D.
Toxicologist
Bureau of Environmental and Occupational Health

Cc: Jennifer Borski, Vapor Intrusion Team Leader, DNR R&R Program
Judy Fassbender, NR Program Manager, DNR R&R Program
Roy Irving, Chief, DHS Hazard Assessment Section, BEOH
Mark Werner, Chief, DHS BEOH

Enc: Summary of DHS response to Request for Assistance: Actions for Trichloroethylene at Acute Risk Levels

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Enclosure: Summary of DHS response to Request for Assistance: Actions for Trichloroethylene at Acute Risk Levels

DNR Ask	DHS Response	Supporting Reference(s)
1) Clarification from DHS that acute risk necessitates immediate action as defined in s. NR 700.03(28), Wis. Admin. Code.	**A)** Immediate action as defined in NR 700.03(28) warranted if: for compounds except TCE = 3x VAL, or 10x VAL carcinogens; TCE w/ women age 15-44 = VAL	**A)** December 7, 2017 DHS letter and EPA OSWER Tech Guide (2015)
2) Clarification from DHS that trichloroethylene (TCE) present in indoor air above the applicable VAL qualifies as an acute risk to women of child-bearing years	**A)** VALs&VRSLs based on EPA RSLs **B)** RSL for TCE is based on immunotox. and fetal cardiac development endpoints **C)** findings confirmed by reviews **D)** also consistent with epi study findings **E)** single exposure during development can have harmful effect **F)** critical development window 3 to 6 weeks **G)** rapid action warranted for TCE > RSL	**A)** EPA tox assessment TCE (2011) **B)** Kiel et al. (2009) Johnson et al. (2003) **C)** EPA OSWER (2014), ATSDR (2014), MADEP (2014), Makris et al (2016), NC DEQ (2018) **D)** Brender et al. (2014), Dawson et al. (1993) **E)** EPA (1991) **F)** Smart and Hodgson (2018) **G)** EPA 2014, EPA Region V (2020)
3) Health-based recommended responses including the definition of critical exposure windows with scientific justification to help inform DNR determination of time lines for immediate (s. NR 700.03(28), Wis. Admin. Code) and interim (s. NR 700.03(29), Wis. Admin. Code) actions in the following scenarios:		
a) TCE is present beyond the envelope of a building at or above the applicable Vapor Risk Screening Level (VRSL)	**A)** evaluate demographics in building **B)** sample indoor air with 24-72 hour TAT **C)** consult w/ women 15-44 about TCE **D)** if TCE >VAL, carbon filtration w/in 48 hours and sub-slab system w/in 2 weeks **E)** if TCE <VAL, perform another indoor air sample and sub-slab system w/in 4-8 weeks	**B)** EPA Region 9, (2014) WI DNR RR800 (2018), EPA Reg V (2020)
b) Non-carcinogenic compounds are present beyond the envelope of a building at or above three (3) times the applicable VRSL	**A)** RfC is estimate, ca. order of magnitude, of concentration w/o harm over lifetime **B)** >3x that level cuts significantly into that safety factor **C)** indoor air sampling with 24-72 hour TAT **D)** sub-slab system w/in 4-8 weeks if >VAL	**C)** EPA Region 9, (2014) WI DNR RR800 (2018), EPA Reg V (2020)
c) Carcinogenic compounds are	**A)** VRSLs est. w/ 10^{-5} cancer risk	WI DNR RR800 (2018), EPA Reg. V (2020)

present beyond the envelope of a building at or above ten (10) times the applicable VRSL	**B)** >10x that exceeds 10^{-4} cancer risk **C)** sub-slab system w/in 4-8 weeks if >10x VRSL	
d) TCE is present in indoor air below the applicable VAL	**A)** verify TCE in sub-slab is not >VRSL **B)** If TCE also <VRSL; one more sampling event **C)** do follow up samples soon as possible if women age 15-44 live in building	WI DNR RR800 (2018), EPA Reg. V (2020)
e) Non-carcinogenic compounds are present in indoor air between the applicable VAL and three (3) times the applicable VAL	**A)** sub-slab system w/in 4-8 weeks **B)** sample to confirm system is effective	WI DNR RR800 (2018), EPA Reg. V (2020)
f) Carcinogenic compounds are present in indoor air between the applicable VAL and ten (10) times the applicable VAL	**A)** sub-slab system w/in 4-8 weeks **B)** sample to confirm system is effective	WI DNR RR800 (2018), EPA Reg. V (2020)
g) TCE is present in indoor air at or above the applicable VAL	**A)** evaluate demographics in building **B)** consult w/ women 15-44 about TCE **C)** carbon filtration w/in 48 hours and sub-slab system w/in 2 weeks	WI DNR RR800 (2018), EPA Reg. V (2020)
h) Non-carcinogenic compounds are present in indoor air at or above three (3) times the applicable VAL	**A)** RfC is estimate, ca. order of magnitude, of concentration w/o harm over lifetime **B)** >3x that level cuts significantly into that safety factor **C)** sub-slab system w/in 4-8 weeks **D)** if >>VAL, consult health officer for actions available under Section 254 WI Administrative Code	WI DNR RR800 (2018), EPA Reg. V (2020)
i) Carcinogenic compounds are present in indoor air at or above ten (10)	**A)** VRSLs est. w/ 10^{-5} cancer risk **B)** >10x that exceeds 10^{-4} cancer risk **C)** sub-slab system w/in 4-8 weeks	WI DNR RR800 (2018), EPA Reg. V (2020)

times the applicable VAL	**D)** if >>VAL, consult health officer for actions available under Section 254 WI Administrative Code	
4) Health-based recommendations for when sampling indoor air at commercial or industrial businesses is necessary in light of the recent Department of Defense study on sewers and utility tunnels as preferential pathways (*Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors And Investigation Protocol*, ESTCP Project ER-201505)	**A)** DHS agrees with DOD study findings **B)** DHS recommends sampling indoor air when soil gas results suggest indoor air levels may be exceeded **C)** Indoor air should always be assessed where TCE is contaminant of concern due to acute reproductive endpoint **D)** when assessing indoor air in commercial buildings, may need to relocate COCs that are used in production during sampling	US DOD ESTCP Project ER-201505 (2018)

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June 6, 2022

Christine Haag
Program Director
Remediation and Redevelopment Program
Wisconsin Department of Natural Resources
101 S. Webster Street
Madison, WI 53707-7921

Subject: DHS response to Request for Assistance: Clarification of single exposure for trichloroethylene (TCE)

Dear Ms. Haag:

The Wisconsin Department of Health Services (DHS) received an email on October 18, 2021, from Vapor Intrusion Team Leader, Jennifer Borski, requesting clarification of what constitutes a *single exposure* for Wisconsin's trichloroethylene (TCE) vapor action level (VAL) of 2.1 $\mu g/m^3$ for residential exposures and 8.8 $\mu g/m^3$ for small and large commercial and industrial exposures. This information is sought to support DHS immediate action recommendations for TCE provided in a letter dated March 25, 2021.

DHS response:

Environmental Protection Agency (EPA) regional screening levels for air are based on inhalation unit risk (IUR) for carcinogenic toxicological endpoints and reference concentration (RfC) for non-cancer endpoints. These toxicological values are based on a daily oral slope factor (cancer) or reference dose (RfD) (non-cancer) exposure parameter (in $(mg/kg\text{-}day)^{-1}$). The current environmental assessment levels are also based on a daily assessment of eight-hour samples for occupational settings and 24-hour samples for residential scenarios.

Based on these observations, the optimally resolved values achievable are daily (8-hour for occupational, 24-hour for residential) exposure and assessment values, and these values constitute a single exposure for TCE for risk evaluation purposes.

Thank you for the opportunity to provide feedback on this topic. Please contact me at (608) 266-6677, or curtis.hedman@wisconsin.gov if you have any follow up questions or comments about this response.

Sincerely,

Curtis G. Hedman

Curtis Hedman, Ph.D.
Toxicologist, Bureau of Environmental and Occupational Health

Cc: Jennifer Borski, Vapor Intrusion Team Leader, DNR R&R Program
Judy Fassbender, NR Program Manager, DNR R&R Program
Roy Irving, Chief, DHS Hazard Assessment Section, BEOH
Mark Werner, Chief, DHS BEOH

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Vapor Intrusion Guidance

Wis. Stat. ch. 292, Wis. Admin. Code chs. NR 700-799

Appendix I – References

Related Guidance
DNR publications and forms referenced in this document include a number beginning with "RR-" or "4400-." Locate these publications and forms by visiting dnr.wi.gov and search for the number.

Find additional DNR guidance on vapor intrusion by visiting dnr.wi.gov and searching "vapor."

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