Vapor Intrusion Mitigation Guidance

Technical Resource Document

San Francisco Bay
Regional Water Quality Control Board

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California Water Boards

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Transmittal Memorandum

To: Interested Parties

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Subject: Update to Vapor Intrusion Mitigation Guidance

The San Francisco Bay Regional Water Board (Regional Water Board) oversees numerous cleanups at properties where vapor-forming chemicals (VFCs) released into the subsurface present a health threat to building occupants due to migration into indoor air, a process termed vapor intrusion (VI).

We have developed this document to aid VI mitigation decisions at sites with VFCs. It provides information about how the Regional Water Board evaluates VI mitigation, including mitigation options, performance monitoring and effectiveness evaluation. It also describes the information needed in various plans and reports to support our evaluations and decisions. The following concepts underlay development of this information:

- VI mitigation is an interim measure and is not considered a substitute for remediation of VFCs in the subsurface.
- VI mitigation decisions, including the selection of specific measures, methods, and means should be site-specific and based on a thorough conceptual site model supported by multiple lines of evidence.
- Monitoring is needed to verify that VI mitigation measures are operating properly and successfully to control VI and limit exposure.

The information provided in this document updates, and replaces, the VI mitigation guidance provided in our 2014 “Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region.” In addition, we have updated our 2019 Fact Sheet for Development on Properties with a Vapor Intrusion Threat to make it consistent with the updated VIM guidance. Additional content will be released as completed and will address other aspects of VI cases (e.g., regulatory framework, investigation, risk assessment, remediation, closure).

Disclaimer

This document is not intended to establish policy or regulation, nor does it represent a new application or interpretation of policy or regulation. Site-specific conditions and multiple lines of evidence are critical to each decision. The guidance is intended to be used in conjunction with professional judgment. Alternative approaches will be considered but should be supported by adequate technical documentation.

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Vapor Intrusion Mitigation

Vapor intrusion (VI) is the migration of chemical vapors from the subsurface into buildings and is a common problem at properties contaminated by vapor forming chemicals (VFCs). VI mitigation (VIM) refers to actions that lessen the amount of subsurface VFCs intruding into buildings, typically by reducing vapor entry and/or diluting vapor concentrations after VFCs have entered a building. Potential VIM measures include short term actions to reduce or eliminate VFC concentrations in indoor air and engineered VIM systems retrofitted to existing buildings or incorporated into the design of new buildings.

VIM measures including VIM systems (VIMS) are not a substitute for cleanup. In general, these measures serve as an interim protective measure until cleanup can be completed. The Regional Water Board regulates VIM operation, maintenance, and monitoring on a case-by-case basis considering the risks and threats from subsurface pollution that exist before, during, or after cleanup.

The main text of the chapter provides information describing the Regional Water Board's current regulatory approach for VIM. In addition, two attachments are included as follows:

- Attachment 1 – Sampling, Analysis, and Measurement Considerations for VI Evaluations
- Attachment 2 – Lines of Evidence for VI Evaluations

1. Approach for Vapor Intrusion Mitigation

This section discusses the Regional Water Board's risk-based approach to VIM decisions, view on the role of remediation and mitigation, importance of VIM monitoring, and the VIM document submittal timeframes.

1A. Current and Future VI Risk-Based VIM Decisions

The need for and selection of specific VIM measures (e.g., sealing floor cracks, installing an engineered VIMS, ongoing monitoring) should be based on current and future VI risk assessments:

- Current VI risk occurs when building occupants are currently being exposed to subsurface contamination via the VI pathway. Data from indoor air sampling is the preferred line of evidence (LOE) for assessing current VI risk.
- Future VI risk includes two aspects: (1) future exposures at existing buildings due to changes to land use, building occupancy, building use (e.g., new or changed ventilation), or building condition; and (2) future exposures in new buildings (e.g., development, redevelopment). Data from subsurface soil gas is the preferred LOE for assessing potential future VI risk.

To evaluate future VI risk, the Regional Water Board considers the following factors that can alter the degree of VFC attenuation during transport from the subsurface source to indoor air:

- Building Conditions – Changes to an existing building can alter its VI susceptibility. New or remodeled buildings may have different susceptibilities compared to previous structures on a property. Specific aspects include:
    - Building design
    - Building structure condition (e.g., settling, modifications, damage from catastrophic events); and
    - Building ventilation operation (e.g., changes to the heating, ventilation, air conditioning).
- Subsurface Conditions – The following activities can alter soil permeability, moisture, or oxygenation and cause subsurface contaminant redistribution:
    - Surface grading, soil removal, or soil import;
    - Trenching and utility installation (creation of potential preferential pathways);
    - Building cover, hardscape, or pavement (i.e., the capping effect can result in increased concentrations in the region beneath the cover/pavement);
    - Landscaping/pavement removal (reduction of capping effect);
    - Irrigation system (increase in soil moisture); and
    - Water table fluctuations.

To account for these changes that could potentially reduce VI attenuation and increase future VI risk, a Regional Water Board approved attenuation factor (AF) should be applied to subslab and/or near-source soil gas data collected near the building (or future building). Approved AFs can be the screening AFs used in the current Regional Water Board Environmental Screening Levels (ESLs; Regional Water Board 2019a) or alternative AFs developed as described in Section 4C.3.b The substitution of groundwater data may be appropriate if collection of representative soil gas or subslab soil gas data is not feasible (e.g., shallow groundwater prevents soil gas sampling, sampling beneath buildings is not allowed).

Ultimately, the decision to implement VIM measures and the selection of specific VIM measures should be site-specific and based on multiple LOEs (see Attachment 2). In general, the Regional Water Board considers the following when approving specific VIM actions to protect current and future occupants from VI:

- Robust conceptual site model (CSM)
    - Characterization of contamination and subsurface conditions
    - Completion of feasible remediation

    - Likelihood of potential changes to the CSM (e.g., subsurface VFC concentration trends)
- Potential for acute or short-term hazard
- Refined risk assessment based on updated CSM and additional LOEs
- Stakeholder preferences and risk perception and tolerance
- Financial assurance and management for ongoing mitigation and monitoring

1B. Relationship Between VIM and Remediation

In general, the Regional Water Board considers VIM as an interim measure that is not a substitute for remediation of VFCs in the subsurface. In most cases, for new construction where a VIMS is needed to protect building occupants, we will not approve the VIMS until remediation to the extent feasible has been implemented. This could affect the local agency's permitting decision for occupancy. Cleanup is the best way to reduce the magnitude of VI exposure that could occur if problems arise with VIMS, and it is the best way to reduce the timeframe over which VIMS are needed. Nonetheless, VIMS are often necessary since achieving cleanup standards may take years given currently available remedial technologies. Additionally, VIM may be the only viable long-term response action where remediation is infeasible (e.g., further concentration reductions are not possible and residual concentrations pose a VI threat).

1C. Importance of VIM Monitoring

The Regional Water Board relies on monitoring to verify that VIM measures are operating properly and successfully controlling VI exposure. This is because VIM measures, including VIMS, are not fail-safe due to potential construction damage, lack of perfect seals, and future changes such as renovation damage, degradation of components, or changes to building occupancy, use, or ventilation. For situations where long-term operation, maintenance and monitoring (OM&M) are required, a VIMS funding plan typically will be needed to make it clear who is expected to fund implementation of the OM&M Plan and the funding mechanism.

1D. VIM Document Submittal Timeframes

This section provides lists of expected VIM documents to be submitted to the Regional Water Board and the expected submittal timeframes for three different types of building situations: buildings with VIM measures, existing buildings where mitigation is provided by the existing design/function (no VIMS), and mitigation by new building design (no VIMS). Recommended content for the VIM documents is provided in the specified sections in the table. All technical documents should be signed by and stamped with the seal of a California registered geologist, a California certified engineering geologist, or a California licensed civil engineer. The VIMS Design Plan and OM&M Plan, specifically, should be signed and stamped by a California licensed civil engineer.

1D.1 Document Lists with Submittal Timeframes

Table 1 – Documents for VIM by Existing Building Design (No VIMS)

Document Title	Submittal Timeframe
VIM Monitoring Plan (Section 8C)	Existing Building - After completion of VI screening. New Building – Prior to building construction.
Long-Term VIM Monitoring Reports and Five-Year VIM Review Reports (Section 8E)	As long as monitoring is required
VIM Incident Reports (Section 8E.5)	30 days after completion of contingency action
Final VIM Monitoring Workplan (Section 8F.1)	When the Regional Water Board agrees suitable conditions are met
Final VIM Monitoring Report (Section 8F.2)	After final VIM monitoring events

Table 2 – Documents for Buildings with VIMS

VIMS Document Title	Submittal Timeframe
VIMS Funding Plan (Section 8A)	Prior to building and/or VIMS construction
VIMS Design Plan (Section 8B)	Prior to building and/or VIMS construction
VIMS Operation, Maintenance, and Monitoring Plan (Section 8C)	After completion of baseline and startup system testing and prior to building occupancy
VIMS Construction Completion Report (Section 8D)	After completion of baseline and startup system testing and prior to building occupancy
Long-Term VIMS Monitoring Reports and Five-Year VIMS Review Reports (Section 8E)	As long as monitoring is required
VIMS Incident Reports (Section 8E.5)	30 days after completion of contingency action
Active VIMS Shutdown Workplan or Passive VIMS Decommissioning Workplan (Section 8F.1)	When the Regional Water agrees suitable conditions are met
Active VIMS Shutdown Report and Passive VIMS Decommissioning Report (Section 8F.2)	After shutdown or decommissioning evaluations complete

Table 3 – Documents for VIM by New Building Design (No VIMS)

Document Title	Submittal Timeframe
VIM Monitoring Plan (Section 8C)	Prior to building construction
Building Construction Completion Report (Section 8D)	After completion of baseline and startup testing and prior to building occupancy
Long-Term VIM Monitoring Reports and Five-Year VIM Review Reports (Section 8E)	As long as monitoring is required
VIM Incident Reports (Section 8E.5)	30 days after completion of contingency action
Final VIM Monitoring Workplan (Section 8F.1)	When the Regional Water Board agrees suitable conditions are met
Final VIM Monitoring Report (Section 8F.2)	After final VIM monitoring events

2. Vapor Intrusion Mitigation Options

In this section, common VIM options are grouped and described as follows:

- Short-term mitigation for existing buildings;
- Engineered VIMS for existing or future buildings;
- Mitigation by building design and function for existing or future buildings;
- Mitigation for contaminated groundwater in contact with a building; and
- Mitigation of potential vapor conduits.

Additional resources for VIM include the Technical Resources for Vapor Mitigation Training (ITRC 2020), the ANSI/AARST standards (ANSI/AARST 2017a, 2017b), and the Vapor Intrusion Mitigation Advisory (VIMA; DTSC 2011b).

2A. Short-Term Mitigation

Short-term mitigation refers to prompt actions taken to quickly reduce or eliminate VFC concentrations in indoor air due to VI. When demonstrated to be effective, these measures can potentially remain in place for longer time periods but may require continued inspections, monitoring, and regulatory oversight. Frequent indoor air monitoring may be needed to confirm these VIM measures are effective and protective, particularly when implemented to address a short-term exposure hazard.

2A.1 Sealing Vapor Entry Points

Vapor entry point refers to any penetration in the building foundation (or subsurface walls) such as cracks, expansion joints, utility conduits, sumps, and elevator shafts, through which subsurface vapors can be transported into the building. Sealing of vapor entry points can limit the locations where vapors can enter. Walls and flooring can prevent locating these features. This action may be ineffective unless most or all entry points are sealed. Sealing materials should be capable of preventing VFC vapor transport, compatible with the surface being sealed, and not contain significant amounts of VFCs.

2A.2 Increasing Ventilation

Opening windows, doors, vents or installing fans within a structure can promote reductions in VFC indoor air concentrations air through mixing and dilution with outdoor air, provided there is not an outside source of VFCs. Ventilation of only an upper building level may exacerbate the "stack effect" (advective flow of air from underneath the building foundation because of the reduction in internal air pressure with increasing height within a building) and draw more contaminated soil gas into the structure. Balancing ventilation between the lowest level and upper levels of a structure (e.g., opening a window on the ground floor when a window on a higher floor is opened) may lessen the stack effect. It is unreasonable to expect that these actions can be maintained over time or be considered a long-term solution to a VI problem.

2A.3 Modifying Building Pressurization and HVAC Systems

Modifying the existing heating, ventilation, air conditioning (HVAC) system can create positive pressure at least within the lower level of the structure to temporarily lessen VI potential. Positive pressure within the building should be consistently maintained to reduce the advective transport of soil gas into the structure. Heating and air conditioning systems may need to be modified from operating on an as-needed basis to operating continuously. This approach is likely to be most effective in newer construction that is relatively energy efficient; it may be less reliable and more costly in older buildings that leak air around windows, doors, and other gaps.

In some buildings, manipulation of the HVAC system may be too complicated to effectively mitigate the VI pathway. Where building pressurization can reduce advective forces, diffusive flow may continue. Therefore, this approach may not be appropriate where subslab soil gas VFC concentrations are significant. It is unreasonable to expect that operating an HVAC system outside the usual range of operations will be maintained over time or be considered a long-term solution to a VI problem. In addition, monitoring the effectiveness of this measure can be difficult. Occupant activities, power outages, and other adjustments to the HVAC system are likely to disrupt efforts to create positive pressure. For example, during recent Bay Area fires, high particulate concentrations in outdoor air required that many HVAC system operations be modified to exclude outdoor air.

2A.4 Treating Indoor Air

Air treatment units (ATUs) are portable air filtering and/or treatment devices placed within a building to improve indoor air quality. The most common air cleaning technology uses a sorbent, typically carbon, to remove gas phase chemicals from the air (USEPA 2017a).

The following factors should be considered when selecting an ATU: physical/chemical properties of the target VFCs, humidity and temperature levels, concentrations of contaminant VFCs and ambient VFCs, and properties of the sorbent. Further details such as unit selection criteria, monitoring recommendations, and system limitations are provided in *Engineering Issue: Absorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air* (USEPA 2017a).

In general, ATUs should only be used as a temporary mitigation measure to reduce the concentration of VFCs in indoor air until a more reliable and effective, longer-term mitigation measure can be implemented. These units may be effective at reducing VFCs in indoor air and should be accompanied by routine indoor air monitoring to verify effectiveness. The difficulty of determining the effectiveness of ATUs over time, and the likelihood, owing to its portability, that an ATU will be moved or turned off by building occupants, make them inappropriate for longer-term mitigation (MassDEP 2016).

2A.5 Relocating Building Occupants

Breaking the exposure pathway by removing the exposed population from the building and limiting building access can be used as a temporary measure until other mitigation options are implemented.

2B. Engineered VIMS

The following sections briefly describe typical components and the more common types of engineered VIM systems (VIMS) employed at cleanup sites that the Regional Water Board oversees.

2B.1 Terminology: Typical System Components

The following general terms, in alphabetical order, are defined for use in this section and throughout the document:

- Alarms/Sensors – Alarms and sensors include devices that make a sound or signal a telemetry to send warning notices (e.g., email, text, call) when there is a power failure or pressure drop.

- Collection Pipes – Perforated pipes installed in a horizontal position in the venting layer. Low-profile vents are similar and serve the same function but typically are rectangular in cross section.
- Conveyance Pipes – Pipes used to convey soil gas include collection pipes, vent riser pipes, and suction points.
- Fans/Blowers – Fans or blowers are used in active VIMS to create negative pressure gradient (i.e., vacuum) and increase air flow.
- Monitoring Ports/Probes – Monitoring ports include access ports on pipes aboveground or installed monitoring probes (e.g., subslab, indoor air) that can allow for diagnostic testing (e.g., vacuum, pressure, air flow) or sample collection for chemical analysis.
- Suction Points – Riser pipes that have a solid riser with a perforated portion typically terminating below the slab. Suction points are typically used for gas extraction as part of subslab depressurization systems installed in existing buildings because installation of a venting layer and collection pipes is not feasible.
- Vapor Barrier – A barrier refers to a material used to prevent or slow vapor transport. Typically, barriers are horizontal but can also be vertical. Traditional barrier materials include liners (e.g., HDPE, geomembranes), spray-applied asphalt-latex membranes, or epoxy floor coatings. In addition, concrete slabs in good condition or slabs that have been sealed can serve as a barrier. Newer barriers typically are multilayered geofabrics designed to increase resistance to physical damage during construction and may incorporate polar materials (e.g., ethylene vinyl alcohol, metallized films) to limit VFC partitioning into and diffusion through the barrier (Di Battista and Rowe 2020). Further information on vapor barriers is presented in Section 3A.5.b.
- Vent Riser Pipes – Solid pipes typically installed in a vertical position inside or outside the building and connect to collection pipes.
- Venting Layer – The venting layer typically underlies the concrete slab and consists of coarse-grained granular fill (e.g., gravel) that allows for rapid vapor transport and propagation of pressure/vacuum. One alternative to a venting layer is an aerated floor, which has lower air flow resistance than granular fill. Aerated floor systems consist of continuous void space beneath the concrete slab typically supported by plastic forms (e.g., small arches) placed prior to pouring of the slab (ITRC 2020).

2B.2 Subslab Depressurization (SSD) Systems

SSD systems use energized fans or blowers to create negative pressure below the building, as compared to the indoor air. This negative pressure gradient prevents soil gas transport into the building (i.e., flow control). Effective VIM using an SSD system requires sufficient pressure to overcome competing forces within the building caused by furnaces, bathroom fans, stove vents, occupant activities (e.g., opening windows and doors), or weather effects (e.g., changes in temperature, wind and barometric pressure) (MassDEP 2016). Excessive subslab depressurization can result in the backdraft of combustion exhaust from natural-draft combustion appliances (e.g., oil/gas furnaces, stoves, fireplaces) such that smoke could be pulled back into a room. The potential for backdrafting should be evaluated during baseline system testing (see Section 3B.3).

Key system components for SSD systems in new construction typically include the following: venting layer, vapor barrier, subslab collection pipes, vent riser pipes, fan, monitoring ports, and alarm system. For existing buildings, instead of venting layers, suction points are installed by coring or trenching through the slab, directional drilling from outside the building, or other methods.

2B.3 Submembrane Depressurization (SMD) Systems

Submembrane depressurization is used for buildings with crawl spaces (i.e., raised foundations) and works similarly to subslab depressurization. For SMD systems, the vapor barrier (membrane) is installed on the ground in the crawl space. Key SMD system components typically include the following: membrane (vapor barrier) installed on the ground in the crawl space, submembrane collection pipes, vent riser pipes, fan, monitoring ports, and alarm system.

2B.4 Subslab Ventilation (SSV) Systems

Subslab ventilation (SSV) systems typically consist of dual piping networks of horizontal subslab pipes in a permeable fill venting layer connected to vertical vent pipes (or stacks) that allow subslab contaminant vapors to discharge to the atmosphere through one piping network and fresh air to recharge through the other piping network. SSV systems may be either active (energized fan) or passive. Due to the lack of an engineered venting layer and vapor conveyance system, SSV systems typically are not used for existing buildings except where the existing subslab materials have high effective diffusion coefficients (e.g., gravel).

Active SSV systems use an electrical fan/blower to continuously withdraw soil gas (resulting in subslab depressurization) or blow outdoor air into the venting layer (resulting in subslab pressurization). Active SSV systems differ from SSD systems by relying on air flow to dilute vapors rather than on a specified pressure gradient to prevent advective flow into the building. Advantages of active SSV include the ability to be operated continuously and a more effective reduction of subsurface VFC concentrations.

Passive SSV systems create suction when vapors in the vertical stack (pipe system) are warmer (less pressure) than outdoor air and when wind moves across the stack, which induces withdrawal of soil gas from the subslab venting layer. To some extent, this venting can reduce the subslab pressure. Wind-driven fans are commonly installed on riser pipes to enhance passive venting. Advantages of passive systems include eliminating the need for electrical energy and permits, whereas disadvantages of passive systems are the lack of continuous dilution and the potential need for more frequent VFC concentration monitoring to ensure effectiveness.

Key system components for SSV systems typically include the following: venting layer, vapor barrier, subslab collection pipes, vent riser pipes, fan (if active), monitoring ports, and alarm system.

2B.5 Crawl Space Ventilation (CSV) Systems

Crawl spaces are short, unoccupied spaces beneath buildings with a raised foundation such that it is not possible to stand up. Crawl space ventilation (CSV) is used for existing crawl space buildings to remove crawl space air and replace it with fresh air from outside vents thus diluting VFC concentrations in crawl space air. A membrane may or may not be deployed depending on crawl space accessibility and conditions. If the crawl space is accessible, SMD is preferred because it is typically more effective. Other considerations for CSV include the potential for backdrafting or freezing of pipes in colder climates. Key CSV components include conveyance piping, fan, monitoring ports, and alarm system.

2B.6 Soil Vapor Extraction and Multiphase Extraction

The use of soil vapor extraction (SVE) or multiphase extraction remediation technologies may provide effective mitigation if the radius of influence of the system can be demonstrated to provide adequate depressurization beneath the foundation of the target building(s) or if vapor concentrations (indoor air or soil gas) are demonstrated to decrease because of SVE operation. In this way, SVE can be used to sever the VI exposure pathway. In some cases, SVE can provide effective mitigation over wide areas with multiple buildings, streets, and utilities (Stewart et al. 2020). Horizontal extraction wells can be considered for buildings where vertical wells are not feasible within the building.

2C. Mitigation by Building Design and Function (No Engineered VIMS)

This section addresses the situation where installed VIMS are not necessary at existing and new buildings due to the inherent ability of the buildings to attenuate VFCs intruding from the subsurface. The amount of VI attenuation observed at individual buildings can vary based on building design, condition, and ventilation/HVAC[1] operation even when the subsurface characteristics (e.g., soil type, contaminant distribution) are the same or similar. The difference in attenuation between buildings with similar designs can be

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[1] HVAC as used in this document refers to all types of heating, cooling, or ventilation systems, both engineered and non-engineered (e.g., windows, doors).

orders of magnitude as demonstrated by the subslab attenuation factor range for the USEPA VI Empirical Database (USEPA 2012c): 0.03 (95th percentile) to 0.0003 (5th percentile). Therefore, the design of the building, in some instances, could be expected to sufficiently limit VI to protect current and/or future building occupants. Nevertheless, post-construction testing and monitoring typically are warranted to demonstrate effectiveness.

2C.1 Existing Buildings

Due to temporal variability, regulatory agencies typically recommend multiple rounds of indoor air sampling at existing buildings where soil gas concentrations exceed VI screening levels. For those buildings where the indoor air results demonstrate that either VI is not occurring or occurring at concentrations well below appropriate indoor air screening levels or Regional Water Board approved criteria, installation of pre-emptive VIMS may not be necessary. This decision depends on many factors (e.g., conceptual site model, results of investigations, remediation, building considerations). Long-term monitoring may still be needed at existing buildings without VIMS until subsurface concentrations have been sufficiently reduced to eliminate the future VI threat—see Section 4B.3.

2C.2 New Buildings

Two common building designs expected to be less susceptible to VI, as compared to slab-on-grade buildings, include raised foundation buildings and enclosed ventilated parking garages.

2C.2.a Open Air Ground Floor Buildings

Open air ground floor buildings (e.g., open-air garages, podium-style construction, buildings raised floor without an enclosed space) typically are well-ventilated enough to break the exposure pathway to upper floors. This is due to height of the open-air ground floor (e.g., 11 feet), which allows for free air movement that can dilute and break the VI pathway. However, potential vapor conduits (e.g., elevators, stairwells, and utilities) should be evaluated as a potential migration pathway for subsurface vapors at all raised foundation buildings. Placing or routing these features away from areas of subsurface contamination is recommended (DTSC 2011b). Crawl space buildings are not equivalent to open-air ground floor buildings—typical crawl space heights are less than 24 inches and may be enclosed, limiting their ability to allow dilution and break the VI pathway.

2C.2.b Enclosed Ventilated Parking Garages

Recently, the Regional Water Board has reviewed proposals for new construction consisting of enclosed ventilated parking garages with overlying commercial or residential spaces where the garage design and operation (ventilation) function as VI mitigation (i.e., there is no separate, engineered VIMS).

The consideration of enclosed ventilated garages as a substitute for an engineered VIMS is relatively new, and there is limited information on the subject (WDNR 2018; MPCA 2019). In general, the California Building Code requires ventilation and pressure measures to prevent airflow from the enclosed garage to occupied spaces. Factors to consider when evaluating enclosed ventilated garages as a substitute for engineered VIMS include:

- Occupancy – Presence of offices or attendant booths where periods of exposure could occur.
- Ventilation – The planned ventilation should be evaluated to estimate the air exchange rate and understand the potential for dilution of intruding subsurface VFCs. The 2019 California Mechanical Code (Chapter 4, Section 403.7) mandates a ventilation rate of 0.75 cubic feet per minute per square foot (cfm/ft^2) (e.g., about 4 exchanges per hour for a garage with an 11-foot-high ceiling). The California Energy Commission allows a lower ventilation rate (0.15 cfm/ft^2) when the system includes carbon monoxide sensors that trigger an increase in ventilation rate once a certain carbon monoxide level is reached (California Energy Code Chapter 4, Section 3.3). The latter, demand-controlled ventilation results in considerably less ventilation (e.g., about 0.8 exchanges per hour for a garage with an 11-foot-high ceiling). Demand-controlled ventilation is commonly used because of the high energy costs associated with high ventilation rate operation.
- Maintenance and Monitoring – The garage should be properly maintained, and operation monitored over time to ensure correct operation and the additional prevention of VI. Garage inspection and periodic effectiveness testing (e.g., garage indoor air sampling) should be conducted.
- Garage Depth – The construction of underground garages may beneficially result in the complete or partial removal of contaminated subsurface media. However, for deeper vapor sources, such construction may shorten the distance between the vapor source (contaminated soil or groundwater) and receptor, potentially warranting additional VIM measures (e.g., waterproofing).
- Elevators/Stairwells in the Garage – The potential for elevators in the garage to provide a complete pathway for VI to the occupied spaces of the building should be considered. VIM measures targeted to these features may be necessary.

2D. Mitigation for Contaminated Groundwater in Contact with a Building

For sites where groundwater is close to or contacts a building foundation, there may be insufficient vadose zone to enable soil gas flow thus precluding SSD or SSV systems as viable mitigation options. Alternatives include:

- Dewatering to enable soil gas flow and use of SSD or SSV;
- Installing a barrier outside the building (new construction) that prevents both water and gas transport; or
- Using mitigation options inside the building (e.g., spray-applied barriers, increased ventilation rates, aerated floors).

2E. Mitigation of Potential Vapor Conduits

Common building features such as elevators, sumps, plumbing fixtures, utility conduits, utility trenches, and sewers can serve as preferential migration routes for contaminated vapors or groundwater to enter a structure. Description of mitigation options for these features are presented herein.

2E.1 Elevators

Elevators can act as discrete entry points for VI where the elevator pit (usually the lowest point in a foundation) is located near the vapor source. Elevator pits commonly are not sealed at the bottom and may be required by code to have drains at the bottom, not connected to sewers, to prevent accumulation of water. Elevators and shafts may act like a syringe when the elevator rises to draw in subslab vapors and transport them to overlying occupied spaces (ITRC 2007; WDNR 2018). For new buildings, the preferred option is to locate elevators away from the areas of significant subsurface contamination. Alternately, it may be possible to seal the elevator pit or equip drains with one-way valves or traps to prevent soil gas and groundwater entry (USEPA 2008). Other mitigations options include venting and positive pressurization.

2E.2 Sumps

Sumps with accumulated water (e.g., groundwater) can allow for direct off gassing into indoor air. Sumps can be fitted with vapor tight lids or sealed around the lid and any piping and electrical penetrations can be sealed using a non-permanent caulk such as silicone.

2E.3 Plumbing Fixtures

Loose toilets can serve as entry point for VFCs within sewers. The toilets can be re-seated with new wax rings and sealed around the base. It is also important that all plumbing traps contain an adequate amount of water to prevent sewer gas entry.

2E.4 Utility Conduits

Inadequately sealed utility conduits can provide vapor entry points into buildings. Conduit seals that prevent soil gas transport can be used to prevent soil gas from migrating through utility conduits into the building. Typically, the seals are created using inert gas-impermeable material (e.g., closed cell polyurethane foam) placed at the termination inside the building and extending for about 6 inches along the interior of the conduit. Appropriate and compatible materials should be used considering building codes.

2E.5 Utility Trenches

Utility trenches are generally used in large buildings (e.g., multi-unit residential, offices, schools, commercial/industrial) for utility runs and may become routes for soil gas to enter the building (DTSC 2011b). Trench dams are constructed along a section of trenches (typically near the edge of the foundation) to prevent soil gas or groundwater from migrating along utility pathways into the building. Relatively impermeable materials (e.g., sand-cement slurry, bentonite-soil mixtures) should be used for trench dam construction.

2E.6 Sewers

VFCs can be transported in sewer pipe air with little attenuation. The potential for VFCs to be transmitted via sewer air into structures is greatest where sewer lines intersect soil source zones and contaminated groundwater. VFCs in sewer air can enter structures via dry p-traps, faulty plumbing seals, or punctured vent pipes. Short-term mitigation options for the sewer VI pathway near the receptor include adding water to dry p-traps and replacing damaged toilet gaskets (Jacobs et al. 2015). Long-term options suggested for the sewer main are sewer venting, installing check valves, lining the sewer pipe, or rerouting the sewer pipeline (Wallace et al. 2017). Any modification of a sewer should only be done with the concurrence or approval of the local sewer utility district.

2F. Mitigation of Petroleum Hydrocarbons

Petroleum hydrocarbons can biodegrade under aerobic (oxygenated) environmental conditions that are found at many sites (USEPA 2012b). The VI threat related to petroleum hydrocarbon contamination in the subsurface is frequently reduced by biodegradation, which occurs under common conditions. Biodegradation by naturally occurring microbes takes place in the water phase (e.g., soil moisture, groundwater). Aerobic biodegradation can reduce the concentration of petroleum vapors in vadose zone soils where there is sufficient oxygen and clean soil between the petroleum contamination and building foundation. In general, oxygenated soil that supports biodegradation is defined as greater than one percent by volume oxygen in soil gas (USEPA 2015b). This phenomenon has been demonstrated with empirical data (Davis

2009; Lahvis et al. 2013; USEPA 2013a). USEPA along with many state and other agencies have developed guidance or policies considering the likelihood for biodegradation. Select petroleum vapor intrusion (PVI) guidance and policies include USEPA (2015b), ITRC (2014), and the State Water Board's Low-Threat UST Case Closure Policy (State Water Board 2012b).

PVI typically is of greater concern where there is less potential for biodegradation to adequately reduce petroleum VFC concentrations between a subsurface source and a building. Examples include situations where the petroleum release is directly beneath a building, large volume releases that can deplete subsurface oxygen, or preferential pathways (e.g., sewers) where the vapors could travel through the air space without biodegradation (McHugh et al. 2010; USEPA 2013a).

Subslab ventilation-type systems can be designed to help maintain oxygen levels below a building, which would promote aerobic biodegradation of petroleum hydrocarbons. Luo et al. (2013) and ITRC (2020) describe an aerobic vapor mitigation barrier technology that is an in-situ method for VI mitigation and remediation at properties with existing buildings situated above petroleum hydrocarbons. The method involves the delivery of atmospheric (ambient) air below and around a building foundation at rates sufficient to maintain aerobic conditions in the vadose zone that act to mitigate VI and can also enhance the remediation of shallow petroleum hydrocarbon subsurface vapor sources.

3. VIMS Design and Construction Considerations

This section presents aspects to be considered during the design and construction phases of an engineered VIMS. Post-construction verification monitoring is described in Section 4, beginning with baseline and startup sampling (Section 4B.2).

3A. VIMS Design

This section describes the factors or features that should be considered when developing a VIMS Design Plan. A VIMS should be designed so that it can sufficiently reduce VFC migration from subsurface sources to indoor air to prevent exposure at unacceptable levels. The VIMS should be designed, built, installed, operated, and maintained in conformance with standard geologic, engineering, and construction principles and practices by appropriately licensed engineers. The system design and installation should be compliant with California Building Code and local permitting agency requirements.

3A.1 Flexible Mode of Operation

Mode of operation refers to whether a VIMS is active (i.e., energized fan) or passive. For most situations, the VIMS should be designed to allow for conversion between active and passive operation. This allows for a passive SSV system to be converted to active mode if sufficient dilution is not achieved with passive ventilation. Conversely, this also allows an active SSD system to be converted to a passive SSV system as contaminant concentrations below the building are decreasing. Adequate justification should be provided if a VIMS is not designed with this flexibility.

3A.2 Subsurface Contamination Conditions

Prior to selecting a VIMS, the area near the building should be adequately characterized to understand the nature and threat posed by the subsurface VFCs and the potential presence of vapor conduits intersecting subsurface contamination. The data should be representative of current conditions. The data evaluation should consider how construction may alter future soil gas distribution below the building (e.g., slab capping effect) and whether current or future utilities intercept subsurface contamination and potentially serve as a pathway for vapor conduit VI. An understanding of the distribution of VFCs beneath the existing/future building footprint helps with the placement of the following:

- Monitoring Points – Designing and installing monitoring points near historical sampling locations helps with comparison between future and historical data and VIMS effectiveness evaluations; and
- Pathway Features (New Construction) – When the VFC distribution is known, features that can serve as pathways into a building or through a building to upper floors (e.g., utilities, elevators, stairwells) can be placed away from hotspots during building design.

3A.3 Groundwater Conditions

The elevation of the groundwater table, including seasonal fluctuations or long-term trends (e.g., sea level rise and groundwater level rise near the San Francisco Bay margin), is an important consideration in selecting the most appropriate VIM method. If the groundwater table is close to the bottom of the foundation floor or slab, there may be insufficient vadose zone to enable soil gas flow. Some options are presented in Section 2.D.

3A.4 Existing Building Design, Operation, and Condition

When designing and installing VIMS at existing buildings, information about the building's design, operation (e.g., ventilation), and overall condition should be used to optimize the VIMS design (NAVFAC 2011a). The following should be evaluated when designing a VIMS for an existing building:

- VI Pathway – It is important to understand how and where VFCs are entering the building to enable development of an effective design. For instance, if VFCs are entering through a vapor conduit, an SSD system may prove ineffective.

- Building Foundation Design and Condition – Drawings and other information (e.g., permits) should be obtained and reviewed to understand the foundation thickness and presence of functioning and abandoned utilities. A building inspection is recommended to observe the foundation to the extent possible, assess its condition, and identify potential vapor entry routes and building features that may affect the installation and performance of VIM measures (e.g., elevator pits, utilities).
- Permeability of Subslab Materials – Permeable fill/soil materials beneath the slab allow for movement of large volumes of air with little pressure drop thus requiring fewer suction points. In contrast, less permeable materials will require more suction points and greater vacuum for effective mitigation. If information on the subslab materials is lacking, small diameter holes can be drilled through the slab to collect samples of the subslab material. Alternatively, pressure field extension testing could be performed to directly evaluate flow characteristics of subslab materials.
- Building Ventilation – The type and expected operation of indoor air ventilation such as HVAC systems or exhaust fans could affect the function of a VIMS. Understanding the location of the building's fresh air intake(s) and windows and doors that could be opened by building occupants is important so that the VIMS exhaust stack can be placed to avoid re-entrainment.
- Occupants and Building Use – Design options should be discussed with current or future building owners and occupants to accommodate their concerns and minimize inconveniences caused by long-term system operation and monitoring (physical hazards, noise, dust, access issues, etc.).

3A.5 System Components

When developing VIMS Design Plans, ANSI/AARST National Consensus Standards for soil vapor mitigation and control in new construction or existing buildings (ANSI/AARST 2017a, 2017b) may be helpful.

3A.5.a General Selection Considerations

The following should be considered when selecting system components and materials:

- Accessibility and Security – Access is necessary for the system and monitoring locations to enable long-term maintenance and monitoring. However, accessibility should be balanced with security to reduce the potential for damage (e.g., theft, weather) or unauthorized deactivation. Labels should be used to identify components, provide safety warnings, and list contact information for questions.
- Composition and Compatibility of System Materials – The composition and compatibility of materials used in the construction of VIMS (e.g., glues, sealants)

should be considered regarding creation of confounding factors (e.g., VFCs in the materials used are the same as site contaminants), chemical compatibility (e.g., low-density polyethylene tubing is not suitable for soil gas sampling; CalEPA 2015), and chemical resistance (e.g., high concentrations of chlorinated VFCs may not be compatible with vapor barriers).

- Longevity and Life of System Components – Equipment has a finite design life, which can impact operation of the system over time (e.g., fan motors wearing out) and should be accounted for in the long-term OM&M plan.

3A.5.b Considerations for Select Components

Considerations regarding specific components are listed below in alphabetical order:

- Ambient Air Inlets – The ambient air inlets should be designed and constructed with the ability to be capped or otherwise closed to prevent ambient air inflow. This ability will aid future curtailment evaluations, discussed in Section 4B.5.
- Collection Pipes – Collection pipes within the venting layer should typically consist of perforated 3-inch pipe or a low-profile product (e.g., 1-inch high by 12-inches wide). The collection piping should be in communication with all areas under the floor slab. Typically, the spacing between runs should be less than 50-feet and the pipes should be at least 15 feet from the building perimeter.
- Sampling Probes/Ports – Permanent sampling probes/ports that allow for repeatable measurements and sampling should be installed during VIMS construction. This avoids drilling through the foundation and vapor barrier (if present) after construction and potentially voiding any warranty (NAVFAC 2011b). The probes/ports can be for subslab soil gas concentration sampling and/or subslab to indoor air pressure differential measurements. The installation plan should consider the following:
    - Accessibility/Security – The ports/probes should be plumbed to terminate either outside the building in a lockable enclosure or in a readily accessible space inside a building. Such placement can reduce disruption to occupants.
    - Labels – The sample tubing should be identified at the access/sampling location.
    - Layout of the Collection Pipes – All ports/probes should be located about midway between the collection pipes and away from building edges where air stagnation is likely to be greatest.
    - Subslab to Indoor Air Pressure Differential Measurements –These ports should be installed through the slab such that the probe/port allows measurement of both the subslab and indoor air pressures.

  - Vapor VFC Samples – The probes/ports should enable vapor collection from within the venting layer (in addition to at least one location beneath any lower vapor barrier that are present along the bottom of the venting layer). Locations within the venting layer should generally be collocated with planned indoor air sampling locations, as discussed in Attachment 1 (e.g., primary living/work areas, suspected subsurface vapor source areas).
- System Power and Monitors – Active mitigation systems require a reliable power source and typically include a monitoring device to directly indicate if the fan/blower or other integral mechanical component is operating within the established operating range (e.g., in-line pressure gage on SSD systems). For situations where loss of power could result in immediate exposure or exposure to chemicals that can cause short-term effects, adding a backup power source should be considered. Typical options for monitoring devices include:
  - Visible and Audible Alarm – Can be monitored from outside of the building and is used to alert building occupants promptly if the system fails (e.g., fan loses power or stops working). Clear instructions (with the name and phone number of a person to be contacted in such an event) should be placed in a visible location.
  - Telemetry System – Used to transmit data to a recording device via telephone or wireless equipment. These systems can transmit operational status (on/off) or other details with appropriate monitoring metrics (e.g., pressure differential, vacuum, air flow, vapor concentrations).
- Vapor Barriers – Vapor barriers commonly used today are multi-component systems with different liner/membrane sheets or composites (geotextiles) and spray-applied membranes. Vapor barriers should be used in conjunction with a venting or depressurization system so that VFC concentrations do not build up beneath the building over time. Reliance on vapor barriers as a standalone mitigation measure can be problematic due to punctures, perforations, tears, and incomplete seals during installation or damage due to later building modifications, settling or damage. Important characteristics for vapor barrier selection include:
  - Thickness – The thickness should be adequate to withstand the rigors of construction (e.g., sufficient tensile strength and puncture resistance). DTSC (2011b) recommends 60-mil or 0.060-inch thickness, and USEPA (2008) suggests 30-mil or greater.
  - Chemical Diffusion – Materials used in typical vapor barriers include high-density polyethylene (HDPE) or rubberized asphalt. Organic contaminants can partition into HDPE and other non-polar organic materials, thus potentially allowing for diffusive transport through these materials. Newer vapor barrier products incorporate polar materials (e.g., ethylene vinyl

    alcohol or EVOH, metallized films) to limit partitioning and diffusion through the barrier (Di Battista and Rowe 2020).
    - Chemical Resistance – Vapor barriers should not degrade from direct contact with significantly contaminated soil or groundwater.
    - Solvent Vapor Transmission – Single layer water vapor or moisture barriers used in standard construction practices are not appropriate or designed to mitigate chemical VI—typically these are relatively thin (e.g., 10-mil or 0.010 inch).
- Vent Riser Pipes – The following should be addressed in the design:
    - Ability to be Capped – The vent pipes should be designed and constructed with the ability to be capped or otherwise sealed to prevent discharge of vapors. This ability will aid future curtailment evaluations, discussed in Section 4B.5.
    - Exhaust Location – The discharge of VIMS effluent should not be a source of chemical exposure (e.g., near/co-located with building HVAC intakes and windows and resulting in re-entrainment) and should meet local Air Quality Management District standards. Typically, riser terminations and fresh air inlets should be greater than 10 feet from any building opening or HVAC intake. Also, riser terminations typically should be at least 1 foot above the roof or parapet walls.
    - Labels – Typically, the pipe should be labeled every 5 feet with a cautionary statement (e.g., potentially hazardous volatile compounds).
    - Interior/Exterior Location – In general, it is preferred to have the riser pipes located outside the building envelope so that, in the event of a leak, VOCs are not directly discharged to indoor air. If riser pipes are located inside buildings, then cast iron piping should be considered. Also, threaded connections or appropriately chemically resistant couplers should be used. In addition, periodic pipe integrity testing or indoor air testing should be considered as part of the monitoring program.
    - Sampling Ports – Vent riser sampling ports should be placed a few feet above the foundation to enable easy access and be proximal to the subsurface.
    - Sloping of Horizontal Riser Sections – Horizontal sections of the riser should be sloped to drain moisture that could block airflow.
- Venting Layer – The venting layer is one of the most critical components of a VIMS. The venting layer typically should consist of a 4-inch-thick gravel layer with less than 2 percent fines. Gravel promotes rapid vapor transport and propagation of pressure/vacuum. The venting layer should extend throughout the footprint of the building. Collection pipes should be vertically centered in the venting layer.

3B. VIMS Construction Considerations

This section describes practices that will promote quality VIMS construction (e.g., inspections, testing, coordination with non-VIM-related contractors trades to reduce potential for damage, detailed documentation). Thorough documentation that a VIMS has been properly constructed can be an important LOE when interpreting post-construction performance measurements (See Section 8D). Inspections, testing, and documentation by an independent third-party construction quality assurance firm/engineer can greatly improve confidence in VIMS construction. For some properties, the Regional Water Board may require the independent, third-party entity to report directly to our case manager.

3B.1 Notifications

Before building or VIMS construction begins, the Regional Water Board and other involved agencies should be notified regarding the schedule. In addition, for new construction, a plan to inform other construction contractors regarding the existence of the VIMS and its components should be developed to reduce the likelihood of inadvertent damage to the system during VIMS- or non-VIMS-related building construction activities.

3B.2 Construction Inspections

During VIMS construction, the building/VIMS should be periodically inspected (e.g., daily) to confirm and document proper construction by properly trained and certified contractors. Inspections should also be performed during non-VIMS-related building construction activities to help ensure that installed VIMS components are not damaged. Components or features to observe include the following:

- Collection Pipes – The collection pipes should be centered vertically in the venting layer.
- Conduit Seals – Utility conduits terminating inside the building should be sealed to reduce potential vapor migration into the building. Typically, conduits should be sealed around vapor barrier penetrations and at the top of slab since the former can be damaged during construction. Typically, polyurethane foam is used. See the VIMA Appendix A for further information.
- Fans/Blowers
    - Monitoring Ports
    - Gauges/Alarms
- Sampling Ports/Probes – These should be installed within a protective conduit where possible. They should be tested and confirmed to be in working order before the concrete slab is poured.

- Vapor Barrier (if applicable) – Placement/application, testing, and documentation of any repairs made
    - Observations – Use of the proper materials, seams, seals around penetrations and the edges of the foundation/footings, and holes or tears.
    - Coupon testing – Confirmation of the thickness of spray-applied barriers by cutting out physical samples, measuring the thickness, and repairing the cuts.
    - Smoke testing – Conducting at least one smoke test to qualitatively demonstrate there are no visible leaks. The smoke test should be conducted after rebar for the foundation is placed. Vapor barrier conditions should be documented at the time of the verification. Leaks detected in the vapor barrier should be repaired and documented.
- Venting Layer – Documentation of depth/thickness measured at several locations and compaction results
- Utility Trenches – Trench dams (or plugs) should be installed to reduce potential vapor migration beneath and into the building. Dams typically consists of bentonite-soil mixtures or sand-cement slurries. See Appendix A of the VIMA (DTSC 2011b) for further information.

3B.3 Post-Construction Inspections and Diagnostic Testing

After VIMS construction, a post-construction inspection should be performed along with appropriate testing of system components to confirm integrity and function. Considerations for the inspections and testing include:

- Air Flow Rate (Active Systems Only) – Measured at the same time as fan vacuum at a fixed location inside each pipe (air flow rate varies across the pipe diameter) using a pitot tube or similar device.
- Backdraft Testing (Active Systems Only) – Conducted if warranted due to the presence of natural-draft combustion appliances (e.g., that oil/gas furnaces, wood stoves, and fireplaces) such that smoke could be pulled back into a room because of the depressurization system. The *Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances* (ASTM 1998) may be used as guidance for determining if backdrafting conditions exist. Carbon monoxide detectors typically should be installed at any home where backdrafting is a possibility.
- Labeling and Contact Information – Ensure all components are properly labeled and that there is contact information for the party responsible for maintaining the system.

- Fan Vacuum (Active Systems Only) – Measured at the same time as PFE using a manometer or similar device with an accuracy of 25 Pascals (0.1 inch of water column). The manometer is mounted on the pipe on the vacuum side of the fan.
- Photographs and descriptions should be used to document elements that will be hidden after construction (e.g., vapor barrier, venting layer, conveyance pipes inside walls), and elements that will remain visible but require future maintenance and monitoring (e.g., fan, gauges, sampling ports).
- Pressure Field Extension (PFE) (Active Systems Only) – PFE testing is also referred to as communication testing or radius of influence testing. Adequate PFE is demonstrated by measurements of negative pressure (vacuum) beneath the slab or membrane relative to indoor air. Further discussion is provided in Section 4A.2. A detailed description of the PFE procedure is presented in Appendix IV of the MassDEP Vapor Intrusion Guidance: Site Assessment, Mitigation, and Closure (MassDEP 2016). Active venting systems may or may not achieve adequate differential pressure in which case other lines of evidence (fan vacuum, air flow rate, and vapor concentration testing) will be needed for system effectiveness evaluations.
- Riser Pipe Leak Testing – Pressurizing the pipe system to a set limit and checking the joints and seals for leaks. This is particularly important where the riser pipes are indoors or near windows given the potential for a completed pathway for VI if the pipes are breached.
- Venting Layer Connectivity Test – Measuring air flow at each vent riser pipe outlet location with the system turned off and again with the system turned on. When the system is active, there should be an observable increase in the flow rate in the downstream direction at each measured outlet location compared to when the system is passive (MPCA 2020).

4. Performance Monitoring and Effectiveness Evaluation

The Regional Water Board's regulatory approach to VIM focuses on using performance monitoring data and information to evaluate the effectiveness of VIM measures. Performance monitoring consists of performance measurements (e.g., sampling and analysis of VFC concentrations in multiple media) and inspections (e.g., observation of visible VIM components, observation of building use, condition, and ventilation). VIM effectiveness evaluations typically involve comparison of VIM performance monitoring data to risk-based criteria to assess current and future VI risk.

This section presents the following:

- Types of performance monitoring and the process/criteria used for VIMS effectiveness evaluations

- Overview of the performance monitoring lifecycle for buildings with and without VIMS
- Building-specific VIM effectiveness evaluations
- Attachment 1 provides a description of sampling, analysis, and measurement considerations for VI evaluations.

4A. Performance Monitoring Components and Evaluation Process

This section presents types of VIM performance measurements and VIM inspections that should be included in typical monitoring plans. In addition, the evaluation process is discussed for VIM performance measurements in the following categories:

- VFC concentrations in air/vapor or groundwater samples
- Subslab to indoor air pressure differential

Results of performance measurements should meet appropriate evaluation criteria to ensure that VIM measures are successfully preventing unacceptable exposure from VI. Typical evaluation criteria include site-specific action levels/cleanup goals or screening levels (when site-specific levels are not developed), and a specified negative subslab to indoor air pressure differential (for depressurization VIMS) to be achieved over the building footprint.

4A.1 VFC Concentration Data

This section presents the VFC concentration sampling objectives and evaluation criteria for each medium. Consistent with standard VI practices, indoor air concentration data should be interpreted considering each available LOE, including both qualitative and quantitative information. Attachment 2 describes the use of multiple LOEs to develop the CSM and support VI pathway evaluations and provides descriptions of many different types of LOEs.

4A.1.a Indoor Air Data

Indoor air sampling data is the primary LOE when evaluating risk to current building occupants because the data indicate the chemicals and concentrations to which occupants are directly exposed. Indoor air data integrate all VI exposure pathways (e.g., soil gas to indoor air, vapor conduit air to indoor air). Indoor air sampling objectives are listed below followed by a description of the corresponding VIM performance evaluation process.

Objective 1 (Indoor Air): *Evaluate whether the VI pathway is complete*

If the VI-related VFCs are detected in indoor air, this could indicate the VI pathway is complete. However, indoor air data should be evaluated considering all available LOEs to determine whether indoor or outdoor sources of VFCs are contributing to indoor air results before concluding that VI is occurring. Typically, the following LOEs should be used:

- Chemicals of Potential Concern – Available subsurface data should be used to identify the chemicals of potential concern (COPCs). In general, COPCs are those chemicals whose concentrations exceed background concentrations (DTSC 2015).
- Comparison of Subsurface and Indoor Air Sampling Results – The following contaminant evaluation options can be helpful LOEs for data interpretation:
    - Comparison of Relative Chemical Ratios in Different Media Samples – Evaluating the ratio between concentrations of different chemicals in soil gas, subslab soil gas, and indoor air samples may help to confirm that indoor air impacts are due to VI. The relative ratios of VFC concentrations in many indoor and outdoor sources (confounding sources) will be distinct from subsurface source-derived VFC ratios. If the ratios of contaminant constituents in the indoor air are similar to the ratios observed in soil gas, one may conclude that the two are linked and that confounding sources are not likely present. This is a reasonable assumption for subslab soil gas because volatile subsurface contaminants will move into indoor air at similar rates under typical conditions (i.e., where vapors are transported into the building primarily through advection).
    - Comparison of Chemical-Specific Attenuation Factors (AF) – If the VFCs detected in indoor air are solely from VI, then the chemical-specific AFs should be similar. VI typically is driven by advection, thus VFCs move at approximately the same rate from beneath the building into indoor air. Therefore, chemical-specific AFs derived from indoor air and subsurface sampling data should be similar among the identified VFCs. If a chemical has a much larger AF than the other VFCs, it may indicate the presence of indoor or outdoor sources of that chemical. For example, the following subslab AFs are calculated: tetrachloroethene (PCE) AF = 0.1, trichloroethene (TCE) AF = 0.0009, and cis-1,2-dichloroethene AF=0.0011. These results suggest indoor or outdoor sources of PCE are contributing to the elevated indoor air concentrations of PCE, in addition to VI. In this example, PCE should not be eliminated in the risk assessment; however, the understanding that indoor and/or outdoor sources are likely present will influence risk management decisions.
- Indicator Chemicals – Contaminant VFCs not common in consumer products or typically not in ambient air (e.g., cis-1,2-dichloroethene) can be indicative of VI when detected in subsurface and indoor air samples.
- Outdoor Air Results – Outdoor air sampling results are used to evaluate whether detections in indoor air samples could be the result of VFCs present in outdoor air, considering frequency and magnitude of detection. In general, VI is not

identified as the likely source of a chemical in indoor air unless indoor air VFC concentrations are greater than those found in outdoor air samples.

- Presence of Non-Subsurface Sources of Indoor Air Contaminants – Consumer products can be an indoor source of VFCs. In addition, building materials and furnishings can absorb VFCs and off gas for some time, even after the primary source (e.g., consumer products) has been removed. Information from building surveys can be helpful to assess the potential contribution of indoor sources.
- Diagnostic Air Results – Diagnostic air samples can be used to help understand whether or how VI is occurring. Examples include air samples collected near vapor entry points (i.e., any penetration in the building foundation or subsurface walls) or potential indoor sources (e.g., consumer products) and air samples collected within vapor conduits (i.e., a subset of potential preferential pathways that provide little or no resistance to vapor flow, such as inside a pipe). For further information regarding diagnostic air sampling, see Attachment 1, Section 10A.5.
- VIMS Installation – For situations where the construction/installation activities and quality control testing have been observed and well documented (e.g., independent third-party verification under Regional Water Board oversight), this qualitative LOE could be used to support the interpretation that indoor air VFC detections may be the result of indoor sources rather than VI.

If the indoor air results appear to be the result of indoor sources (e.g., greater chemical of concern concentrations in indoor air than in the subsurface and outdoor air), consider resampling to assess whether indoor air concentrations dissipate over time. If the results can be reasonably attributed to an indoor source (e.g., bonding glue) through a building survey and diagnostic air testing (e.g., containerizing suspect building material samples then sampling and analyzing the headspace air), then further evaluation may not be necessary. If the results pose a significant health risk and cannot be attributed to non-subsurface sources, further evaluation is warranted and could consist of diagnostic air sampling (see Attachment 10A.5) or use of other methods (see Attachment 2).

If the VI pathway is determined to be complete, this may indicate the VIMS was not installed and/or functioning as designed, even if indoor air concentrations are below the VI risk-based evaluation criteria. This information can help inform decisions related to the management of future VI risk and the frequency of OM&M activities.

Objective 2 (Indoor Air): *Confirm that mitigation measures are effectively reducing VI-related indoor air contaminant concentrations to less than indoor air ESLs or alternative criteria approved by the Regional Water Board*

If the VI pathway is determined to be complete, the indoor air data should be compared to either the residential or commercial indoor air ESLs or alternative criteria approved by the Regional Water Board to assess the VI risk. Section 4C.1.b provides a discussion regarding developing alternative criteria, including for enclosed garages that are unoccupied and where garage air samples are used to assess risk to occupants of overlying floors. Cumulative risk and hazard should be calculated and evaluated using the points of departure (1x10^{-6} cancer risk and HI of 1) when there are several VFCs. If there are no unacceptable VI-related risks, this indicates the mitigation measures are currently effective and monitoring should continue pursuant to the monitoring plan. If there are unacceptable VI-related risks, appropriate contingency action(s) should be conducted (e.g., convert a passive VIMS to active operation, modify the VIMS, implement additional mitigation measures), in accordance with the contingency plan.

4A.1.b Subslab Soil Gas Data

Subslab soil gas (subslab) sampling results are used for characterizing the concentrations of VFCs immediately below a slab-on-grade building that can migrate into indoor air. In general, subslab samples should be collected from permanent subslab probes, and Section 3A.5 describes sampling probe/port design considerations. Subslab sampling objectives and the corresponding evaluation process are discussed below. For crawl space buildings with a membrane (vapor barrier) installed on the ground surface, samples collected from beneath the membrane may be considered similar to subslab soil gas.

> ***Objective 1 (Subslab):*** *Evaluate subslab VFC sampling data collected during an indoor air sampling event to determine the source(s) of VFC detections in indoor air.*

Compare the relative VFCs concentrations in subslab data to the indoor air data, considering available LOEs, as described in Section 4A.1.a (Indoor Air Data Objective 1). For example, VI is unlikely to be a source of indoor air contamination if subslab VFC concentrations are less than indoor air VFC concentrations and the vapor conduit VI pathway has been separately ruled out.

> ***Objective 2 (Subslab):*** *Determine if there are areas of stagnation within the venting layer of a VIMS.*

Evaluate subslab data collected from locations away from ambient air inlets and collection pipes to assess spatial and temporal variability in VFC dilution below the building. Large variability between results from different sampling locations and/or sampling events could indicate areas of stagnation within the venting layer. This information can be used as a LOE when determining if:

- A ventilated VIMS should be operated in active or passive mode; or
- Maintenance/modification of the ventilated VIMS is necessary.

> ***Objective 3 (Subslab):** Estimate indoor air VFC concentrations for VI risk calculations.*

Subslab data and a Water Board approved AF (e.g., building-specific AF as described in Section 4C.3.b or screening AF if a building-specific AF is not developed) can be used to estimate indoor air concentrations. Estimated indoor air concentrations should be compared to the same risk-based criteria specified for Objective 1 in the indoor air data section above. Cumulative risk and hazard should be calculated and evaluated using the points of departure when there are several VFCs. If subslab data are consistently less than risk-based levels and near steady state conditions have been reached, then it may be appropriate to conduct a system shutdown or decommissioning evaluation (Section 4B.5). If subslab data indicate unacceptable risk, the appropriate contingency action(s) should be conducted (e.g., sample indoor air, convert a passive VIMS to active operation, modify the VIMS, implement additional mitigation measures), in accordance with the contingency plan.

4A.1.c Outdoor Air Data

Outdoor air sampling results are used to determine potential influences of outdoor air contamination on indoor air quality, thus aiding with indoor air data interpretation and determining VI contribution. Outdoor air sampling objectives and corresponding evaluation process are discussed below.

> ***Objective 1 (Outdoor Air):** Evaluate outdoor air VFC concentration data collected during an indoor air sampling event to determine the source(s) of VFC detections in indoor air.*

Compare the relative VFCs concentrations in the outdoor air to the indoor air data, as part of the multiple LOEs interpretation of indoor air data described in Section 4A.1.a (Indoor Air Data Objective 1). For example, outdoor air sources of VFCs are likely impacting indoor air if the VFC concentration in outdoor air is similar to, or greater than, the indoor air VFC concentration.

> ***Objective 2 (Outdoor Air):** Evaluate the potential for VFCs exhausted from the VIMS to enter the building (e.g., via HVAC operations) and impact indoor air quality (re-entrainment).*

For situations where vent riser terminations or fresh air inlets are within 10 feet of any building opening or HVAC system intake, then outdoor air samples should be collected near VIMS discharge locations. Alternatively, vent riser air samples should be collected (see Vent Riser Air – Objective 2). Compare outdoor air results from samples collected near VIMS discharge locations to either the residential or commercial indoor air ESLs or alternative criteria approved by the Regional Water Board to evaluate re-entrainment. Re-entrainment is the unintended reentry of VFC-containing exhaust air discharged from a VIMS (or remediation system) into a building (ANSI/AARST 2017b). If the outdoor air VFC concentrations collected near VIMS discharge locations exceed the indoor air criteria, then re-entrainment is a concern. If the outdoor air data indicate that re-entrainment is unlikely, modifications to the system are not warranted. If the outdoor air data indicate an unacceptable indoor air risk, appropriate contingency action(s) should be conducted (e.g., treat vent riser air prior to discharge to outdoor air, modify the VIMS). Vent riser air sample data can be used to evaluate re-entrainment when outdoor air samples are not collected near VIMS discharge locations.

4A.1.d Vent Riser Air Data

The vent riser air sampling objectives and corresponding evaluation process are discussed below.

> ***Objective 1 (Vent Riser Air):*** *Determine whether the VFC discharge/exhaust rate exceeds Air District permit requirements.*

Vent riser air sampling results are primarily used by the Air District (rather than the Regional Water Board) as part of determining whether the discharge/exhaust rate exceeds the daily allowable discharge for permitted VIMS.

> ***Objective 2 (Vent Riser Air):*** *Evaluate potential for the re-entrainment exposure pathway*

The vent riser air data can be compared with indoor air and outdoor air data as an additional LOE to assess whether indoor air VFC concentrations are potentially the result of re-entrainment. If subsequent vent riser air sampling concentrations do not increase, this indicates the re-entrainment pathway continues to not be an issue. However, if vent riser air concentrations significantly increase, outdoor air should be sampled to assess the re-entrainment pathway.

4A.1.e Crawl Space Air Data

Crawl space air sampling results are used for characterizing VFC concentrations in crawl spaces that may enter the overlying building and degrade indoor air quality. VFCs in crawl space air samples can be the result of subsurface and/or other sources and therefore require supporting LOEs for data interpretation. Crawl space air sampling objectives and corresponding evaluation process include:

> ***Objective 1 (Crawl Space Air):*** *Evaluate crawl space air VFC sampling data collected during an indoor air sampling event to determine the source(s) of VFC detections in indoor air.*

Compare the relative VFCs concentrations in crawl space air data to the indoor air and outdoor air data, as part of the multiple LOEs interpretation of indoor air data described in Section 4A.1.a (Indoor Air Data Objective 1). For example, VI is unlikely to be a source of indoor air contamination if crawl space air VFC concentrations are less than indoor air VFC concentrations or are similar to outdoor air VFC concentrations.

Objective 2 (Crawl Space Air): *Determine if there are areas of stagnation within the crawl space of a CSV or SMD system.*

Evaluate crawl space air data collected from locations away from ambient air inlets to assess spatial and temporal variability in VFC dilution within the crawl space. Large variability between results from different sampling locations and/or sampling events could indicate areas of stagnation within the crawl space. This information can be used as a LOE when determining if:

- Maintenance or modification of the CSV or SMD system is necessary; or
- The mode of operation should be active or passive.

Objective 3 (Crawl Space Air): *Estimate indoor air VFC concentrations for VI risk calculations.*

If VFCs detected in crawl space air samples are from the subsurface, the crawl space air can be used to estimate indoor air concentrations assuming a crawl space to indoor air AF of 1 (consistent with USEPA 2015a) or an alternative AF approved by the Regional Water Board. Cumulative risk and hazard should be calculated and evaluated using the points of departure when there are several VFCs. If crawl space air data are consistently less than risk-based levels, then it may be appropriate to conduct a system shutdown or decommissioning evaluation (Section 4B.5). If crawl space air data indicate unacceptable risk, appropriate contingency action(s) should be implemented (e.g., sample indoor air, convert a passive VIMS to active operation, modify the VIMS, perform additional mitigation measures), in accordance with the contingency plan.

4A.1.f Exterior Near-Source Soil Gas Data

Exterior near-source soil gas (as described in Attachment 1, Section 10F) sampling results are used for characterizing VFCs emitted into soil gas from subsurface sources in soil and groundwater. For situations where the groundwater is shallow or the building is in contact with groundwater and soil gas data cannot be collected, then groundwater data should be used as the primary subsurface data LOE. The exterior near-source soil gas sampling objective and corresponding evaluation process are discussed below.

Objective (Near-Source Soil Gas): *Characterize subsurface vapor source strength over time to support the assessment of future VI risk.*

The exterior near-source soil gas data should be compared to either the building- or site-specific criteria approved by the Regional Water Board or the soil gas VI ESLs (if alternative criteria have not been developed). Section 4C.3 provides a discussion regarding developing alternative criteria. Cumulative risk and hazard should be calculated and evaluated using the points of departure when there are several VFCs. If the exterior near-source soil gas concentrations are less than or trending toward the applicable risk-based criteria, then VIM measures may not be necessary for future buildings.

4A.1.g Groundwater Data

Groundwater sampling results are used for characterizing VFCs in groundwater that can potentially be emitted into soil gas for VI assessment. Reliance on groundwater data for VI evaluation is not preferred due to uncertainty in predicting VFC partitioning from groundwater to soil gas and transport through the capillary fringe. However, for situations where the groundwater is shallow or the building is in contact with groundwater and soil gas data cannot be collected, groundwater data should be used as the primary subsurface data LOE. The groundwater sampling objective and corresponding evaluation process are discussed below.

> ***Objective (Groundwater):*** *Characterize subsurface vapor source strength over time to support the assessment of future VI risk.*

The groundwater data should be compared to the groundwater VI ESLs or alternative criteria approved by the Regional Water Board. Section 4C.3 provides a discussion regarding developing alternative criteria. Cumulative risk and hazard should be calculated and evaluated using the points of departure when there are several VFCs. If groundwater concentrations are below or trending toward the applicable risk-based criteria, then VIM measures may not be necessary for future buildings.

4A.2 Subsurface to Indoor Air Pressure Differential Measurements

Measuring the pressure difference between the subsurface and indoor air (pressure differential) indicates whether subsurface VFCs are potentially migrating into the building (i.e., depressurized building interior) or not (i.e., pressurized building interior) (USEPA 2015a). This is analogous to using the flow direction and gradient when interpreting groundwater data. These measurements should be made from permanent installations as described in Section 3A.5. The subsurface to indoor air pressure differential ($\Delta P_{SS\text{-}IA}$) measurement objective and corresponding evaluation process are discussed below.

> ***Objective ($\Delta P_{SS\text{-}IA}$):*** *Confirm that VI is not occurring for VI risk assessments.*

Subsurface vapors are likely migrating into a building through vapor entry points in locations of the building where positive $\Delta P_{SS\text{-}IA}$ readings are observed. Pressure differential measurements collected from sampling points throughout the building and during different seasons can be used to evaluate the effectiveness of VIMS. In addition,

$\Delta P_{SS\text{-}IA}$ readings can be useful in determining the potential worst-case season for long-term VI sampling at all buildings.

For depressurization VIMS, $\Delta P_{SS\text{-}IA}$ measurements collected from locations throughout the building and during different seasons should all have negative readings of at least 0.02 inches of water column, unless an alternative criterion is developed and approved by the Regional Water Board (see Section 4C.4). This $\Delta P_{SS\text{-}IA}$ criterion is based on USEPA (2008), which indicates that achieving a $\Delta P_{SS\text{-}IA}$ of about -4 to -10 Pascals (-0.02 to -0.04 inches of water column) over the building footprint is considered adequate to mitigate VI. Positive $\Delta P_{SS\text{-}IA}$ measurement readings may indicate that a depressurization VIMS was not installed correctly and/or is not operating as designed. Modification or repair of the VIMS likely is warranted if positive $\Delta P_{SS\text{-}IA}$ readings are observed.

Positive $\Delta P_{SS\text{-}IA}$ readings are expected to occur, some of the time, at buildings with passive VIMS or VIM by building design. For these buildings, $\Delta P_{SS\text{-}IA}$ data (concurrent with indoor air sampling) are primarily used as a LOE to help interpret the source of the indoor air VFC detections during a VIM effectiveness evaluation. For example, a reliable trend of negative $\Delta P_{SS\text{-}IA}$ readings observed throughout a building indicates VFC concentrations detected in indoor air are unlikely to be from VI.

4A.3 Inspections of VIM Measures

The following describes the three general types of inspections related to VIM measures:

- Building Inspections – Building inspections should be conducted to observe building and property conditions as they relate to potential changes in VI risk. Annual building inspections are recommended and are particularly important at buildings where ongoing indoor air monitoring is not occurring. The following is a list of typical building/site conditions that should be observed/checked:
  - Building Condition and Use – The building should be inspected to determine whether there have been changes in condition or operation that would potentially increase VI susceptibility or risk (e.g., building damage, foundation work, subsurface utility repairs, new subsurface utilities, HVAC system operation change, changes in occupancy, change in use).
  - Monitoring Probes/Ports – Check to make certain the valves to the probes are closed.
  - Property Status – Determine whether there have been changes to property ownership, land use, or zoning.
- Enclosed Garage Inspections – Document whether the opening/doors are open, closed, or blocked. Inspect any garage fans and document whether they are operational.

- VIMS Inspections – VIMS observations and system components testing should be performed to confirm integrity and function of the system. Initial post-construction VIMS inspections will typically involve more testing, as described in Section 3B.3. Considerations for the long-term monitoring inspections include:
    - Alarms/Sensors – Should be visible and correctly function.
    - Fans/Blowers – Should correctly operate without excessive noise.
    - Labeling on Components – Should be intact and legible.
    - Monitoring Probes/Ports – Should be closed and in good condition.
    - Vapor Barrier – Since direct observation is not possible, the condition of the vapor barrier should be inferred based on information about the building (e.g., no foundation work, utility repairs, new utilities, tenant improvements, or damage).
    - Vent Riser Pipes – Vents should be clear, and pipes should not be damaged, cracked or blocked. For passive systems, wind-driven fans should be clear of debris and able to freely spin. Verify that nothing has been added near the riser termination that would cause concern (e.g., air intake, change in rooftop use).
    - Air Flow Rate (Active Systems Only) – Measured at the same time as fan vacuum at a fixed location inside each pipe (air flow rate varies across the pipe diameter).
    - Fan Vacuum (Active Systems Only) – Measured at the same time as ΔPSS-IA.
    - Photographs and descriptions of elements that require maintenance (e.g., fan, gauges, sampling ports).

Issues identified during inspections should be addressed in timeframes commensurate with their severity and in accordance with the Contingency Plan. Commonly encountered issues should be dealt with in accordance with the Contingency Plan along with potential or pre-planned responses (e.g., indoor air sampling). The need for preventative maintenance depends upon the life expectancy and warranty for the specific component/part, as well as visual observations over time. Maintenance and repairs are appropriately documented and reported in the long-term monitoring reports.

4B. VIM Performance Monitoring Lifecycle

This section describes the different phases of the monitoring lifecycle, from initial screening through decommissioning (determining that a VIMS is no longer necessary). Generic long-term performance monitoring frequency recommendations for each phase are also provided. The broader issue of case closure should be evaluated in accordance with the Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites (Regional Water Board 2009). For petroleum underground storage tank release cases, closure must be evaluated using the State Water Resources Control Board's Resolution 2012-0062, Low-Threat Underground Storage Tank (UST) Case Closure Policy (LTCP), which became effective August 17, 2012 (State Water Board, 2012b).

Tables 4 through 7 indicate when the different types of performance measurements may be appropriate. Not all performance measurements may be needed for each monitoring event.

4B.1 Indoor Air Screening (Existing Buildings without VIMS)

For existing buildings without a VIMS where nearby subsurface VFC concentrations and other LOEs indicate a VI threat, an indoor air screening investigation is typically performed. The investigation should consist of at least two[2] seasonal sampling periods to determine whether VI is occurring and, if so, whether the VIM is warranted. In general, a building inspection and all applicable performance measurements discussed in Section 4A should be included in each sampling event, as shown in Table 4. The sampling events should be conducted in different seasons (e.g., cold/wet and warm/dry weather).

For buildings where HVAC operations are utilized (e.g., heating, use of exhaust fans, open window or doors), one of the seasonal sampling periods described above should include HVAC-On/Off Sampling to determine the effects of the HVAC operation on VI, provided it is safe and feasible to do so. For further information regarding HVAC-On/Off Sampling, see Attachment 1, Section 10A.4.

4B.2 Baseline and Startup Sampling

Baseline and startup sampling should be conducted at buildings (existing or new construction) with VIMS and at new construction with VIM by building design. Baseline sampling refers to performance measurements taken before the VIM measure is operational whereas startup sampling occurs after the VIM measure is functioning. Baseline data and information serve as a reference against which future changes can be recognized, measured, and compared. As such, baseline and startup sampling data/information are necessary for evaluations of VIM effectiveness. In addition, baseline sampling provides a comparative benchmark for future shutdown and decommissioning evaluations.

For existing buildings, the need to collect new data after VIMS installation, versus relying on previously collected data to assess baseline conditions, can be evaluated considering the age and representativeness of available data. For new construction, baseline data collected after construction is complete are critical because development

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[2] In some instances, it may be necessary to include additional sampling events. For example, in situations where indoor air concentrations are slightly above screening levels or when subsurface concentrations are increasing, additional sampling events can help support decision-making.

activities (e.g., grading, trenching, utility installation, new building construction, placement/removal of paving) can cause changes in subsurface characteristics (e.g., soil permeability, soil moisture, oxygenation, redistribution of contaminants), and/or building characteristics (e.g., design, condition, HVAC system).

The following factors should be considered in determining which type of performance measurements and sampling conditions are needed during baseline and startup sampling.

- Type of Performance Measurements – All applicable performance measurements described in Section 4A should be performed to help evaluate baseline conditions except where adequate justification is provided. The same performance measurements should also be included during startup sampling to enable comparison of the two datasets. However, resampling of exterior near-source soil gas (as described in Attachment 1, Section 10F) and groundwater during startup is not typically necessary since startup of active VIMS or garage fan operation is not likely to impact near-source soil gas and groundwater conditions.
- Sampling Conditions
    - VIMS Installation, Building Completion, Interior Finishes – Baseline and startup performance measurements (e.g., VFC concentrations in subslab and soil gas, and pressure measurements) should be collected after the building and/or VIMS construction are complete (e.g., windows, doors, and HVAC system installed at new construction). Ideally, indoor air sampling at new buildings is performed prior to the completion of the interior finishes (installation of flooring, wall treatments, cabinetry, etc.). This reduces the potential for confounding results from target VFCs in the building materials. Alternatively, the building could be allowed to vent after interior finishes are completed and before indoor air sampling.
    - Steady State Subslab/Submembrane Conditions – The time required for vapors to reach near-steady state (equilibrium) concentrations at a given location varies based on the distance between the source and the upper boundary (e.g., ground surface, building foundation), gas-filled porosity, and chemical-specific retardation coefficients (Jourabchi and Lin 2021). For existing buildings where the CSM indicates the time since the release far exceeds the time to reach steady state conditions, steady state vapor concentrations may equilibrate relatively quickly (e.g., days) after a typical VIMS retrofit (e.g., installation of suction points). However, for new construction, it may take a long time (e.g., months, years) to rebound and establish steady-state conditions depending on the depth of soil disturbance (e.g., grading, fill placement, moisture conditioning for compaction). Based on this understanding, the following timeframes are recommended before conducting post-construction baseline sampling:

        - Existing Buildings – Seven days is recommended to allow steady-state conditions to be reached for existing buildings where VIMS retrofit activities only require minor disturbance to the subgrade region.
        - New Construction – Thirty days are recommended to allow for steady-state conditions to begin to be re-established.
    - VIM Measure Operation – The VIM measure (i.e., active/passive VIMS, ventilation in an enclosed garage, or ventilation below a raised foundation) should be operated as follows during the baseline and startup period:
        - Baseline – The VIM measure should be inoperative, with any VIMS/garage fans turned off, vent pipes capped, ambient air inlets closed, and building openings (e.g., doors, windows) closed.
        - Startup – The VIM measure should be operated in the planned mode (e.g., active or passive) for 7 days prior to performance measurements.
    - HVAC Operation – The appropriate HVAC operation conditions during indoor air sampling should be determined in coordination with the Regional Water Board. While indoor air sampling is generally performed under typical HVAC operation conditions, indoor air sampling under alternative conditions (e.g., HVAC-Off) can be important for diagnostic purposes (e.g., evaluating whether HVAC operation influences VI). Discussion of the factors for consideration is included in Attachment 1, Section 10A.4.
- Inspections – All applicable inspections described in 4A.3 should be conducted during both the baseline and startup sampling events.

Tables 5 through 7 present the generic recommended baseline and startup monitoring for ventilation VIMS, depressurization VIMS, and VIM by new building design, respectively.

4B.3 Long Term Monitoring (Buildings with or without VIMS)

The purpose of long-term monitoring is to verify that the VIMS or building design/function continues to effectively mitigate VI. Ongoing monitoring is needed in situations where subsurface contamination poses a future VI risk (due to potential changes in the building or VIMS [if installed], increasing concentrations, etc.). The long-term monitoring phase begins after initial VI screening (for VIM by existing building design) or after startup sampling (for VIMS at new or existing buildings and VIM by new building design), assuming initial sampling has demonstrated there is no current unacceptable VI risk to building occupants. Generally, long-term monitoring should be performed under typical building use and HVAC operation conditions.

Generic long-term performance monitoring frequency recommendations are presented in Table 4 (VIM by Existing Building Design), Table 5 (Ventilation VIMS), Table 6 (Depressurization VIMS), and Table 7 (VIM by New Building Design). The first year of long-term monitoring is expected to include more frequent measurements to confirm the effectiveness of VIM during different seasons and to determine the likely worst-case season for timing the monitoring in future years. Startup sampling is considered to represent the first quarter of Year 1 long-term monitoring at buildings with VIMS or VIM by new building design, as indicated in Tables 5 through 7.

Provided that effective VIM has been demonstrated during the screening or startup sampling phase, long term monitoring for VIM effectiveness can be focused as described in the following subsections.

4B.3.a VIM by Existing Building Design (No VIMS)

Performance monitoring should include annual building inspections in addition to performance measurements during each monitoring event. The long-term, primary performance measure for VIM by existing building design can be VFC concentration sampling of subslab soil gas, crawl space air, and/or indoor air within a garage; whichever is most applicable based on the building design. This assumes a correlation between the selected primary performance measurement and indoor air data has already been established during the screening phase. Outdoor air sampling should be performed concurrent with any crawl space or garage indoor air samples to help assess the presence of any outdoor sources of VFCs that could influence the crawl space or garage air results. For buildings away from the release area, where multiple rounds of indoor air testing have demonstrated that VI is not occurring, near-source soil gas or groundwater VFC monitoring may be substituted as the primary long-term performance measure. Indoor air sampling in occupied spaces may be triggered as a contingency action if the building survey or performance measurements suggest changes in conditions that can influence VI.

4B.3.b Ventilation VIMS

Performance monitoring should include annual building inspections in addition to VIMS inspections and performance measurements during each monitoring event. The long-term, primary performance measure for ventilation VIMS can be subslab soil gas VFC concentration sampling in the venting layer or crawl space air VFC concentration sampling, if applicable. Outdoor air sampling should be performed concurrent with any crawl space air samples to help assess the presence of any outdoor sources of VFCs impacting the crawl space. Other performance measures are included in the third quarter of the first year of long-term monitoring to accomplish the following:

- Confirm the system is operating properly and successfully during different seasons and confirm there is no potential for re-entrainment;

- Assess soil gas VFC rebound beneath new construction; and
- Determine the worst-case season for timing the annual monitoring in future years.

After Year 1, monitoring of indoor air generally is not necessary, except when triggered as a contingency action. In situations where it is determined that a VIMS needs to be converted from passive to active mode of operation, the long-term monitoring schedule should be restarted at the beginning of Year 1 monitoring, as shown in Table 5.

4B.3.c Depressurization VIMS

Performance monitoring should include annual building inspections in addition to VIMS inspections and performance measurements during each monitoring event. The long-term, primary performance measure can be subsurface to indoor air pressure differential measurements. Vacuum pressure at the fan/blower should only be used as a surrogate for subsurface to indoor air pressure differential measurements after at least one year of data documenting a positive correlation between the two types of measurements. If adequate negative subsurface to indoor air pressure differential is not achieved, then subslab soil gas concentration testing should be substituted at the same frequency recommended for pressure testing. Other performance measures are included in the third quarter of Year 1 to accomplish the following:

- Confirm the system is operating properly and successfully during different seasons with no re-entrainment;
- Assess soil gas VFC concentration rebound below new construction; and
- Help determine the worst-case season for timing the monitoring in future years.

After Year 1, monitoring of other performance measures (e.g., indoor air, subslab) besides pressure differential measurements generally is not necessary, except when triggered as a contingency action. In situations where a depressurization VIMS needs to be modified, the long-term monitoring schedule should be restarted at the beginning of Year 1 monitoring, as shown in Table 6.

4B.3.d VIM by New Building Design (No VIMS)

Each performance monitoring event should include an annual building inspection in addition to garage inspections and performance measurements. The long-term, primary performance measure for VIM by new building design (i.e., raised foundation or enclosed ventilated parking garage) is subslab and/or garage indoor air VFC concentration sampling. Other performance measures are included in the third quarter of the first year of long-term monitoring to accomplish the following:

- Confirm the system is operating properly and successfully during different seasons;
- Assess soil gas VFC rebound beneath new construction; and

- Determine the worst-case season for timing the annual monitoring in future years.

After Year 1, monitoring of indoor air in occupied spaces generally is not necessary, except when triggered as a contingency action. In the event that additional mitigation measures are required, the monitoring schedule should be adjusted as needed.

4B.4 Five Year Review Monitoring

The purposes of a five-year review (FYR) are: (1) verify the VIM measures remains effective; (2) evaluate whether changes to VIM measures are needed; and (3) remind all project contacts (e.g., owner, occupants, VIMS engineer, regulatory agency) of the presence and need for the VIM measures. Evaluation of the VIM measures and the determination of protectiveness should be based on and sufficiently supported by data and observations.

As part of the FYR, consider indoor air sampling in addition to the recommended long-term monitoring performance measures. In some instances, this data may be needed to confirm that the previously documented correlation between indoor air data and the typically monitored performance measurements has not changed to verify the VIM measures remains effective. If indoor air sampling is included, other performance measures (e.g., outdoor air sampling) should be included to help interpret the source(s) of indoor air VFC detections.

4B.5 Curtailment Monitoring

Curtailment monitoring refers to sampling and inspections needed to demonstrate that (a) no further monitoring is needed for a building without VIMS (Final Monitoring); (b) passive operation is likely to be protective for buildings with active VIMS (Shutdown Monitoring); or (c) that no further monitoring is needed for a building with passive VIMS (Decommissioning Monitoring). The three types of curtailment monitoring are described in the subsections herein. In general, curtailment monitoring can begin when all of the following conditions are demonstrated:

- There is no current VI exposure risk
- Subsurface vapor sources have been remediated to the extent feasible
- Multiple LOEs support that residual subsurface contamination will not pose a future VI risk at buildings with passive VIMS operation (to begin shutdown monitoring) or at buildings without VIMS operation (to begin VIMS decommissioning or final monitoring at building without VIMS).
- No other changes in the CSM are expected that would increase the future VI risk (e.g., subsurface VFC concentrations are stable or decreasing, more sensitive land or building use, or groundwater pumping that causes plume migration)

4B.5.a Final Monitoring for Buildings without VIMS

For final monitoring at buildings (existing or new construction) without VIMS, the recommendations and evaluation criteria are the same as those used during five-year reviews (Section 4B.4).

4B.5.b Shutdown Monitoring for Active VIMS

Shutdown monitoring should consist of two events: an initial sampling event to confirm that the passive mode of operation is effectively mitigating VI followed by an additional monitoring event performed in a different season for all relevant media. One of the two events should be performed during the previously established worst-case season. If the results of each event indicate that the passive mode of operation is effectively mitigating VI, the VIMS can continue in the passive mode—otherwise, the VIMS should be reactivated, and the shutdown process terminated. The goal for each event is to demonstrate that indoor air sampling results and/or predicted indoor air results (based on subslab sampling results and an approved AF) are less than indoor air ESLs or alternative criteria approved by the Regional Water Board.

The initial sampling event should be performed not long after shutdown (e.g., within a week). The subsequent sampling during a different season allows for observation of seasonal variability and rebound in subsurface soil gas concentrations while the active VIMS is inoperative. After both events, if the results of the monitoring indicate that the passive mode of operation is effectively mitigating VI, then subsequent monitoring should start with the Year 1, Quarter 2 long-term monitoring for a ventilation VIMS (Table 5), or as agreed upon with the Regional Water Board based on the potential for rebound of soil gas concentrations. Depending on an active system's area of influence, soil gas concentrations beneath a building may not reach steady-state conditions for months or years following shutdown. Hence, the frequency of long-term monitoring in the passive mode may need to be increased based on the expected or demonstrated rebound rate of soil gas concentrations.

As shown in Table 6, performance measurements for depressurization VIMS include both vapor concentration sampling and subslab to indoor air pressure measurements.

4B.5.c Decommissioning Monitoring for Passive VIMS

Decommissioning monitoring should consist of two events: an initial sampling event to confirm that the building, without a functioning passive VIMS, is effectively mitigating VI followed by an additional event performed in a different season for all relevant media. One of the two events should be performed during the previously established worst-case season. The vent pipes and ambient air inlets should be capped/closed so that the VIMS is inoperative during decommissioning since it is not possible to guarantee these pipes will not get blocked in the future. The goal for each monitoring event is to demonstrate that indoor air sampling results and/or predicted indoor air results (based on subslab soil gas sampling results and an approved AF) are less than indoor air ESLs or alternative criteria approved by the Regional Water Board. If the results of each event indicate that the building without a functioning passive VIMS is effectively mitigating VI, the decommissioning process can continue—otherwise, the vents and ambient air inlets should be uncapped to restore passive VIMS function and the decommissioning process should be terminated.

For buildings where indoor air sampling is needed and HVAC operations are utilized (e.g., heating, use of exhaust fans, open window or doors), one of the sampling events described above should include HVAC-On/Off Sampling to determine the effects of the HVAC operation on VI, provided it is safe and feasible to do so. For further information regarding HVAC-On/Off Sampling, see Attachment 1, Section 10A.4.

The initial sampling should be performed not long after the vent pipes and ambient air inlets are capped (e.g., within a week). The subsequent sampling during a different season allows for observation of seasonal variability and potential rebound in subsurface soil gas concentrations without a functioning passive VIMS. If the results of the decommissioning monitoring indicate that the building conditions, without a functioning passive VIMS, are protective, then a passive VIMS is no longer necessary. Hence, monitoring can cease.

As shown in Table 5, performance measurements include both vapor concentration sampling and subslab to indoor air pressure measurements.

4B.6 Monitoring Adjustments

Depending on the specifics of the building, the VIM type, site characteristics, and performance monitoring results, adjustments to the performance measurements and monitoring frequency may be made with sufficient justification and approval by the Regional Water Board. The parameters that influence monitoring frequency may include changes in the VI threat level, reliability of the VIM measure or system, changes to the building, long-term trend information, or other information/data. Also, adjustments to the type of data being collected may be needed.

4B.7 VIM Monitoring Tables

Table 4 – Monitoring for Mitigation by Existing Building Design (No VIMS)

	Screening: Year 1, Initial Season	**Screening:** Year 1, Opposite Season	**LTM:** Years 2 - X, Annual WCS	**LTM:** 5 Year Reviews WCS	**Final:** Year X, Initial Season	**Final:** Year X Opposite Season
Inspections	✓	✓	✓	✓	✓	✓
Pressure Differential (Subsurface to Indoor Air)	⟐	⟐		⟐	⟐	⟐
Outdoor Air*	✓	✓	⟐	⟐	⟐	⟐
Indoor Air*	✓	✓		⟐	⟐	⟐
Subslab Soil Gas or Crawl Space Air*	✓	✓	✓	✓	✓	✓
Near-Source Soil Gas*	✓	✓	○	○	○	○
First Groundwater*	✓	✓	○	○	○	○

✓ = Include in monitoring plan
⟐ = May be included in monitoring plan based on building/site-specific information
○ = Select site-specific frequency to establish long-term trend of VI threat level for evaluating case closure
Opposite Season = If the initial season is cold/wet, the opposite season would be warm/dry or vice versa
LTM = Long-term monitoring
WCS = Worst case season
Year 2 - X = Every year until curtailment, excluding those when a 5-Year Review is completed
5-Year Reviews = Reviews conducted every 5 years until monitoring is no longer needed
* Vapor forming chemical concentration

Table 5 – Monitoring for Ventilation VIMS (SSV, CSV Systems)

	Baseline: Year 1 Q1, Vents Capped	**Startup:** Year 1 Q1, VIMS Operational	**LTM:** Year 1 Q2	**LTM:** Year 1 Q3	**LTM:** Year 1 Q4	**LTM:** Years 2 - X, Annual WCS	**LTM:** 5 Year Reviews WCS	**Shut-Down or Decom:** Year X, Initial Season	**Shut-Down or Decom:** Year X, Opposite Season
Inspections	✔	✔	✔	✔	✔	✔	✔	✔	✔
Pressure Differential (Subslab to Indoor Air)	⟐	⟐					⟐	⟐	⟐
Outdoor Air*	✔	✔	⟐	⟐	⟐	⟐	⟐	⟐	⟐
Vent Riser Air*	✔	✔					⟐	⟐	⟐
Indoor Air*	✔	✔					⟐	⟐	⟐
Subslab Soil Gas or Crawl Space Air*	✔	✔	✔	✔	✔	✔	✔	✔	✔
Near-Source Soil Gas*	✔		○	✔	○	○	○	○	○
First Groundwater*	✔		○	✔	○	○	○	○	○

✔ = Include in monitoring plan
⟐ = May be included in monitoring plan based on VIMS design, mode of operation, and building- or site-specific information
○ = Select site-specific frequency to establish long-term trend of VI risk for evaluating case closure
Opposite Season = If the initial season is cold/wet, the opposite season would be warm/dry, or vice versa
LTM = Long-term monitoring
Q = Quarter
Year 2 - X = Every year from the second year until curtailment, excluding those years when a 5-Year Review is completed
5-Year Reviews = Reviews conducted every 5 years until monitoring is no longer needed
WCS = Worst case season
Decom = System decommissioning
* Vapor forming chemical concentration

Table 6 – Monitoring for Depressurization VIMS (SSD/SMD Systems)

	Baseline: Year 1 Q1, Vents Capped	**Startup:** Year 1 Q1, VIMS Operational	**LTM:** Year 1 Q2	**LTM:** Year 1 Q3	**LTM:** Year 1 Q4	**LTM:** Years 2 - X, Annual WCS	**LTM:** 5 Year Reviews WCS	**Shut-Down:** Initial Season	**Shut-Down:** Year X, Opposite Season
Inspections	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure Differential (Subslab to Indoor Air)	✓	✓	✓	✓	✓	✓	✓	⟐	⟐
Outdoor Air*	✓	✓		⟐			⟐	⟐	⟐
Vent Riser Air*	✓	✓					⟐	⟐	⟐
Indoor Air*	✓	✓					⟐	⟐	⟐
Subslab Soil Gas or Crawl Space Air*	✓	✓	⟐	✓	⟐	⟐	⟐	✓	✓
Near-Source Soil Gas*	✓		○	✓	○	○	○	○	○
First Groundwater*	✓		○	✓	○	○	○	○	○

✓ = Include in monitoring plan
⟐ = May be included in monitoring plan based on VIMS design and building- or site-specific information
○ = Select site-specific frequency to establish long-term trend of VI risk for evaluating case closure
Opposite Season = If the initial season is cold/wet, the opposite season would be warm/dry, or vice versa
LTM = Long-term monitoring
Q = Quarter
Year 2 - X = Every year from the second year until curtailment, excluding those years when a 5-Year Review is completed
5-Year Reviews = Reviews conducted every 5 years until monitoring is no longer needed
WCS = Worst case season
Decom = System decommissioning
* Vapor forming chemical concentration

Table 7 – Monitoring for Mitigation by New Building Design (No VIMS)

	Baseline: Year 1 Q1, Limited Ventilation	**Startup:** Year 1 Q1, Full Ventilation	**LTM:** Year 1 Q2	**LTM:** Year 1 Q3	**LTM:** Year 1 Q4	**LTM:** Years 2 - X, Annual WCS	**LTM:** 5 Year Reviews WCS	**Final:** Year X, Initial Season	**Final:** Year X, Opposite Season
Inspections	✔	✔	✔	✔	✔	✔	✔	✔	✔
Pressure Differential (Subslab to Indoor Air)	⟐	⟐					⟐	⟐	⟐
Outdoor Air*	✔	✔		✔		✔	✔	✔	✔
Indoor Air*	✔	✔					⟐	⟐	⟐
Garage Indoor Air*	✔	✔		✔		✔	✔	✔	✔
Subslab Soil Gas*	✔	✔	✔	✔	✔	✔	✔	✔	✔
Near-Source Soil Gas*	✔		○	✔	○	○	○	○	○
First Groundwater*	✔		○	✔	○	○	○	○	○

✔ = Include in monitoring plan
⟐ = May be included in monitoring plan based on building- or site-specific information
○ = Select site-specific frequency to establish long-term trend of VI risk for evaluating case closure
Opposite Season = If the initial season is cold/wet, the opposite season would be warm/dry, or vice versa
LTM = Long-term monitoring
Q = Quarter
Year 2 - X = Every year from the second year until curtailment, excluding those years when a 5-Year Review is completed
5-Year Reviews = Reviews conducted every 5 years until monitoring is no longer needed
WCS = Worst case season
* Vapor forming chemical concentration

4C. Building-Specific VIM Effectiveness Evaluations

This section discusses the development of building-specific VIM effectiveness evaluations. A building-specific VIM effectiveness evaluation can include use of averaged performance measurement data and/or alternative risk-based criteria when appropriate conditions are met. In contrast, initial VI risk assessments typically use maximum sampling concentrations and screening levels. Proposals for building-specific VIM effectiveness evaluation approaches should be included in the VIMS Design Plan or Monitoring Only Plan for buildings without VIMS. A thorough scoping meeting conducted before submitting evaluation proposals can reduce the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence. Alternative evaluation approaches will be considered, provided there is adequate technical justification.

4C.1 Indoor Air

Indoor air data is compared to risk-based criteria to assess current VI risk for VIM effectiveness evaluations. This section discusses how to properly average indoor air sampling results and/or develop building-specific risk-based indoor air criteria for VI risk assessments used to support VIM effectiveness evaluations.

4C.1.a Averaging Indoor Air Data

At buildings with sufficient indoor air data collected over space and/or time, VIM effectiveness evaluations based on average indoor air VFC concentrations may be appropriate. A 95 percent upper confidence limit on the arithmetic mean (95% UCL) indoor air concentration should be used as the reasonable maximum exposure (RME) concentration. Robust datasets typically include the collection of at least eight sample locations and/or at least eight sampling events (USEPA 1992). Until the Water Board approves the use of a statistical average, the maximum concentration should be used as the RME to estimate risk.

Averaging over space should only include indoor air samples from areas of the building within the same HVAC zone or unit within a multi-unit building. Estimating a building-wide RME concentration may not be appropriate if indoor air concentrations differ substantially between areas of the building. The building-wide RME should be protective of all building occupants and should consider the time each receptor spends in specific areas of a building.

Averaging over time should only occur if indoor air concentrations are relatively stable and/or decreasing. If concentrations suggest a potential short-term exposure risk (e.g., TCE), averaging is generally not recommended.

4C.1.b Building-Specific Risk-Based Criteria for Indoor Air

Maximum or averaged indoor air VFC concentrations can be compared to Water Board approved building-specific risk-based criteria. The most typical option for changes to indoor air risk-based criteria involve adjustments of exposure factors based on current site-specific building use information (e.g., amount of time the building is occupied). However, use of exposure assumptions less conservative than the recommended default values may require institutional controls to ensure that building access/use restrictions are maintained and monitored and that all relevant parties are aware of the building use restrictions.

For multi-story buildings where the lowest floor(s) are unoccupied (e.g., buildings with enclosed garages with overlying residential or commercial floors), alternative indoor air criteria can be developed for the unoccupied lower floors to predict VI risk to occupants on overlying floors accounting for attenuation as vapors migrate upward between floors of a building. This option assumes that the vapor conduit pathway has been evaluated and ruled out. Regional Water Board staff recommend the use of an inter-unit vertical AF of 0.1, which is derived from a study of tobacco smoke transfer between units in multifamily buildings in Minnesota (CEE 2004). In this study, the average of the interunit flow between ground and upper floors was 0.1 (1/10) for six multifamily buildings. The interunit flow was greater on the upper floors, attributed to the stack effect in the colder Minnesota climate. Given the limited number of buildings in this study and the lack of similar studies, applying the average from this Minnesota study is reasonably conservative, given the generally milder California climate in the San Francisco Bay area.

Empirical data (indoor air from an overlying occupied floor and underlying an unoccupied floor) can be used to estimate a building-specific, lower to upper floor inter-unit vertical AF. This AF could be used to develop building-specific risk-based criteria for the unoccupied floor. Due to the potential temporal and spatial variability in indoor air, a reliable current AF would need to be based on a robust dataset: sampling at multiple locations over multiple seasons. Building-specific risk-based criteria based on current building conditions may not represent future VI risk considering the potential for changes in building condition and ventilation (e.g., settling, modifications, damage, different ventilation system). Therefore, buildings should be monitored for changes in these factors when alternative risk-based criteria are used for VIM effectiveness evaluations.

4C.2 Crawl Space Air

Crawl space air data is compared to the risk-based criteria to predict current indoor air concentrations to assess current VI risk for VIM effectiveness evaluations. This section discusses how to properly average crawl space air samples and/or develop building-specific crawl space to indoor air AFs for VI risk assessments used to support VIM effectiveness evaluations.

4C.2.a Averaging Crawl Space Air Data

Crawl space air samples can be averaged following similar guidelines recommended for averaging indoor air data, as discussed in Section 4C.1.

4C.2.b Building-Specific Risk-Based Criteria for Crawl Space Air

The purpose of risk-based crawl space air criteria is to enable crawl space air data to be used to predict current indoor air risk rather than sampling indoor air. Crawl space air criteria are developed dividing indoor air risk-based criteria (see Section 4C.1) by a crawl space to indoor air AF. Initial VI risk assessments typically use the USEPA recommended crawl space to indoor air AF of 1. However, empirical data (indoor air and crawl space air) can be used to develop a building-specific crawl space air AF to develop building-specific risk-based criteria for crawl space air. Due to the potential temporal and spatial variability in both indoor air and crawl space air, a reliable current AF would need to be based on a robust dataset: sampling at multiple locations over multiple seasons.

Building-specific risk-based criteria based on current building conditions may not represent future VI risk considering the potential for changes in building occupancy, use, and conditions (e.g., settling, modifications, damage, different ventilation system). Therefore, buildings should be monitored for changes in these factors when alternative risk-based criteria are used for VIM effectiveness evaluations.

4C.3 Subsurface Data

Subsurface (e.g., subslab, soil gas, and groundwater) VFC concentration data is compared with risk-based criteria in VIM effectiveness evaluations to enable the prediction of potential:

- Current indoor air risk when indoor air sampling is infeasible; and
- Future indoor air risk.

This section discusses how to properly average subsurface samples and/or develop building-specific risk-based subsurface criteria for VI risk assessments used to support VIM effectiveness evaluations.

Subslab soil gas data is the preferred subsurface LOE for predicting indoor air risk when evaluating VIM effectiveness. However, near-source soil gas can be used if subslab sampling is infeasible. Alternatively, groundwater VFC concentrations data may be the only viable subsurface data LOE for VIM evaluations when groundwater is shallow or in contact with the building.

4C.3.a Averaging Subsurface Data

Averaging subslab (substitute near-source or groundwater, as needed) VFC concentrations may be appropriate for VIM effectiveness evaluations in some situations.

However, site-wide spatial averaging is not typically recommended because building specific risk may be underestimated as only VFC concentrations near a building can be reasonably anticipated to migrate towards the building.

A 95% UCL subslab concentration can be determined for a building once a sufficient number of samples have been collected (in space and/or time) and used to predict current and/or future indoor air risk and hazard from VI exposure. A robust dataset is needed for statistical approximation, which usually implies the collection of at least eight samples (USEPA 1992). In addition, the following applies to averaging over space (lateral and vertical) and time:

- Spatial averaging should generally only include subslab samples from areas of the building within the same HVAC zone or unit within a multi-unit building and where the foundation is not segmented (e.g., grade beams). Averaging may not be appropriate if subslab concentrations differ substantially between areas of the building (e.g., hot spots) and should be discussed with the Regional Water Board case manager.
- Averaging soil gas samples from different depths within the same sample location is not recommended because the average may not be representative of conditions under the building due to the slab capping effect, as described in ESL User's Guide Section 5.1.1 (Regional Water Board 2019b).
- Averaging over time should only occur if subslab or soil gas concentrations are relatively stable and/or decreasing. If concentrations suggest a potential short-term exposure hazard (e.g., TCE), averaging is generally not recommended.
- If subslab sampling is not feasible, averaging exterior near-source soil gas data over space should only be conducted if all samples are distributed in a manner representative of vapors migrating from a subsurface source to the building. Averaging may be conducted only when concentrations near a building are generally homogeneous (e.g., a building impacted from an upgradient release to groundwater).

Point or averaged subsurface VFC concentrations can be compared to building-specific VIM effectiveness criteria. Typically, subsurface based criteria are developed by applying VI AFs to indoor air criteria (based on generic or building-specific indoor air exposure factors). Examples of building specific AFs, for buildings with or without VIMS, that could be used to develop subsurface VIM effectiveness criteria are discussed below.

4C.3.b Building-Specific Risk-Based Criteria for Subsurface Data

Risk based criteria for subsurface data are developed by dividing indoor air risk-based criteria (see Section 4C.1) by a subsurface to indoor air AF. Initial VI risk assessments typically use the recommended subsurface to indoor air AFs (e.g., 0.03 for soil gas to indoor air AF). This section discusses how to develop building-specific subsurface to indoor air AFs to be used in building-specific risk-based criteria for subsurface media. Predicted building-specific AFs for redevelopments likely will need to be confirmed with post-construction verification sampling. This is particularly true of sites with very shallow contamination (soil and/or groundwater) that could potentially intercept the future building's subsurface utility lines (e.g., sewer) creating a potential vapor conduit into a building.

Subslab to Indoor Air Building-Specific AFs

Options for developing building-specific subslab soil gas to indoor air AFs at current and future buildings where the vapor conduit VI pathway has been ruled out are discussed in this section.

- Building-Specific VFC Concentration Data – A building's subslab to indoor air AF can be calculated from current indoor air and subslab soil gas data. In general, a reliable current AF is based on a robust dataset including sampling at multiple locations over multiple seasons. However, a current building-specific AF may not represent future VI risk considering the potential for changes in building conditions (e.g., settling, modifications, damage, different ventilation). Therefore, some buildings will still need to be monitored for changes that could increase VI risk even if measured AFs demonstrate VIM is currently effective (See Section 4C.3).
- Empirical VI Database Analysis – This involves considering the results of published empirical VI databases (see Attachment 2, Section 11.I) as part of a multiple LOE evaluation to bracket a range of potential future AFs. In general, this typically results in the selection of an applicable generic empirical AF that is greater than the building's currently measured subslab to indoor air AF to account for potential increases in VI due to building changes.
- Subslab Pneumatic Methods – See Attachment 2, Section 11.H.7.

Near-Source Soil Gas to Indoor Air Building-Specific AFs

Options for development of building specific near-source soil gas to indoor air AFs at current and future buildings where the vapor conduit VI pathway has been ruled out are discussed in this section.

- Empirical Data – Paired near-source soil gas and subslab samples can be used to a determine building-specific, source to subslab AF, as illustrated in Figure 5-4 of the ESL User's Guide. The source to subslab AF can then be multiplied by the USEPA subslab AF of 0.03 or other justified potential future subslab AF to develop a near-source soil gas to indoor air AF. For situations where there is no existing building, multi-depth soil gas samples potentially could be used to develop a source to subslab AF. This can be acceptable provided that the ground surface is paved/covered, and that pavement/cover is evaluated and determined to be adequate to cause the slab capping effect.

- Mathematical Modeling – See Attachment 2, section 11.H.5.
- Petroleum-Specific Considerations – For petroleum VFCs, a bioattenuation factor may additionally be used in developing a building-specific AF provided that current/future site-specific conditions near the building support subsurface biodegradation. For further information, see ESL User's Guide Section 5.4.4.

Groundwater to Indoor Air Building-Specific AFs

The purpose of groundwater criteria for VIM effectiveness evaluations is to enable groundwater data to be used to predict indoor air risk, typically when groundwater is shallow or in contact with the building. Options typically include the following:

- Empirical Data – A building's groundwater to indoor air AF can be calculated from current indoor air and groundwater data. In general, a reliable current AF is based on a robust dataset including sampling at multiple locations over multiple seasons. However, a current building-specific AF may not represent future VI risk considering the potential for changes in building occupancy, use and conditions (e.g., settling, modifications, damage, different ventilation system). Therefore, some buildings will still need to be monitored for changes that could increase VI risk even if measured AFs demonstrate VIM is currently effective (See Section 4B.3).
- Mathematical Modeling – See Section 5.4.3 of the ESL User's Guide (Regional Water Board 2019b) and Attachment 2, section 11.H.5.
- Petroleum-Specific Considerations – For petroleum VFCs, a bioattenuation factor may additionally be used in developing a building-specific AF provided that current/future site-specific conditions near the building support subsurface biodegradation. For further information, see ESL User's Guide Section 5.4.4.

4C.4 Subslab to Indoor Air Pressure Differential

Pressure differential measurements are used in VIM effectiveness evaluations to determine the VFC transport direction between the subsurface and indoor air. As indicated in Section 4A.2, the Regional Water Board's recommended subsurface to indoor air pressure differential ($\Delta P_{SS\text{-}IA}$) criterion is a negative reading of at least 0.02 inches of water column. Historically, this $\Delta P_{SS\text{-}IA}$ was specified to enable a typical radon contractor to quickly and easily verify an induced negative pressure differential relative to the natural fluctuations in the $\Delta P_{SS\text{-}IA}$ of a building from wind gusts, occupants' activities, exhaust appliance operation, thermal convection (e.g., the "stack effect"), and HVAC operations (ESTCP 2018a). While values greater than negative 0.02 inches of water column may be protective, effectiveness should be demonstrated. Such a demonstration likely would involve more extensive diagnostic testing and additional LOEs (e.g., subslab tracer testing, mass flux monitoring, and mathematic modeling) (ESTCP 2018a)—see Attachment 2, Section 11.H.7 (Subslab Pneumatic Methods). This additional level of effort may be most appropriate for large and/or complex buildings.

In some instances, the Regional Water Board may approve the use of subslab to outdoor air pressure differential ($\Delta P_{SS\text{-}OA}$) as an alternative to $\Delta P_{SS\text{-}IA}$ where it is not possible to measure the latter (e.g., access permission, infeasibility of installing subslab probes). For these situations, the $\Delta P_{SS\text{-}OA}$ criterion should account for the potential range of outdoor air to indoor air pressure differential values to ensure that there is a negative $\Delta P_{SS\text{-}IA}$ regardless of the outdoor air pressure influences on indoor air. Therefore, a $\Delta P_{SS\text{-}OA}$ criterion will typically be significantly less than the $\Delta P_{SS\text{-}IA}$ criterion of negative 0.02 inches of water column. Only specially designed SSD systems will likely be able to achieve such criterion (e.g., systems with vapor barriers above and below venting layer).

5. Contingency Actions

Contingency actions are potential and pre-planned response actions for situations where a VIMS is not properly and successfully operating or evidence indicates this is likely to occur (e.g., noisy fan, wind turbine stuck, damaged components). Discovery of problems may be through telemetry systems, routine inspections, monitoring results, notifications by owner/property manager, etc. Situations can range from power failures to catastrophic events (e.g., earthquakes), and contingency actions include problem assessment and corrective action. Corrective actions typically range from basic troubleshooting to upgrading and re-starting the system. Implementing short-term mitigation measures may be necessary if the system is down for an extended period.

Contingency actions due to unfavorable monitoring results may include but are not limited to:

- resampling and analysis;
- more frequent monitoring;
- indoor air sampling and analysis;
- diagnostic testing (See Attachment 1, Section 10A.5);
- pressure differential testing between the first occupied floor and the garage (ventilated garages);
- converting a passive VIMS to active operation; and
- implementing short-term mitigation measures (e.g., indoor air treatment, sealing the floors or other conduits).

The response time for implementation of contingency actions should be consistent with the nature and magnitude of the VI threat. Notification to the owner and occupants should be provided when the system is inoperative for a significant period of time or when significant changes are needed (e.g., converting from passive to active, implementing short-term mitigation measures).

6. Community Engagement

The Regional Water Board requires community outreach as part of the investigation and cleanup process for all sites. Community outreach related to VIM includes communication with the owners and occupants of buildings and properties that are specifically affected. It may also include communication with broader segments of the community, particularly when public buildings and spaces, such as schools, could be affected, or when there is significant community interest.

The following are examples of outreach activities that typically relate to VIM:

- Notice of Work Activities – The party responsible for the VIM should provide appropriate notice to the property owner and occupants prior to any work at the building.
- Property Access – An access agreement between the property owner, any occupants, and the party responsible for the VIM should be executed to enable inspections and monitoring activities. Access agreements will need to be re-executed with the new owner when buildings are sold.
- Notice of Testing Results – The results of VIM performance monitoring should be communicated promptly to building owners and occupants. A plan detailing specifically how the results will be communicated to building owners and occupants should be provided in the OM&M Plan. The following should be considered when indoor air concentrations demonstrate an unacceptable VI risk:
    - Consultants should notify the Regional Water Board case manager as soon as possible if indoor air concentrations exceed acute/short-term exposure hazard-based levels (e.g., USEPA Accelerated Response Action Levels for TCE or Office of Environmental Health Hazard Assessment's Acute Reference Exposure Level for elemental mercury vapor). The Regional Water Board will use this information to promptly decide if they need to issue a Proposition 65 notice to the applicable county contacts.
    - Schedule a meeting and/or issue a letter or fact sheet to the concerned parties (building occupants, owners). These communications should generally be used to discuss/convey the results, explain the meaning of the results with respect to our health protective levels, provide next steps to be conducted by whom and when, relay the need for additional building/property access, answer questions, and provide contacts for additional information.

Current and future owners and occupants of buildings should be aware of any VIM measures at the building and the associated OM&M activities. Land use covenants can be used to communicate to both current and future building owners any land or building use restrictions or requirements associated with the VIM measures at the building. See Section 7 for more information about institutional controls.

7. Institutional Controls

In the context of VI mitigation, institutional controls (ICs) typically are administrative and legal controls restricting activities and uses of a property to help minimize the potential for exposure to contamination and/or protect the integrity of the VI mitigation measure (e.g., adequate maintenance, monitoring, funding). measure is implemented measure ICs can be used to increase the likelihood that appropriate parties are aware of the VI risk and of the VIM measures needed to protect the occupants of a building. A VIMS funding plan will make it clear who is expected to fund implementation of the OM&M Plan and the funding mechanism.

Examples of ICs pertinent to VIM include:

- Requirements for:
    - Notifications from the responsible party to owners and occupants regarding the following:
        - The presence, purpose, and function of the VIMS;
        - Changes in system operation (e.g., system failures, conversion from passive to active, shut down of an active system, and system decommissioning); and
        - Prompt notification of any condition posing an immediate threat to building occupants.
    - Notifications from the responsible party to the Regional Water Board regarding the following:
        - Planned activities that could alter VIMS effectiveness (e.g., building remodel, addition);
        - Damage to the building that could alter VIMS effectiveness (e.g., fire, earthquakes, power outage); and
        - Any condition posing an immediate threat to public health, safety, or the environment.
    - Reasonable Access – Requirements may be needed to ensure access to the property is allowed for VIMS operation, maintenance, and monitoring. If the responsible party does not own the property on which the VIMS will be installed and operated, an access agreement should be developed and executed between the responsible party and landowner. The access rights outlined in the agreement could be binding on future landowners and occupants of the property. These agreements typically indicate that if the owner or tenant refuses access, the Regional Water Board may hold the

    property owner responsible for operating, maintaining, and monitoring the VIMS.

- Prohibitions against:
    - Specific land uses (e.g., no use as a school, day care facility, or residence);
    - Site activities that could interfere with the VIM measure or alter the distribution of subsurface contamination (e.g., excavation, dewatering) unless performed in accordance with a Regional Water Board-approved Site Management Plan.

In addition to these ICs, for properties where there is residual subsurface contamination, the Regional Water Board typically requires a site management plan to document the procedures and protocols to be followed during construction, maintenance activities, and long-term management of residual contamination. These procedures are intended to minimize exposures to workers, occupants, and property users and ensure that contaminated materials are properly managed, and any engineering controls are restored, if disturbed. Such plans also include provisions for management and notifications should unanticipated conditions be encountered (e.g., buried tanks). These documents should be uploaded to GeoTracker.

Enforcement mechanisms such as legal instruments or agreements can be used to ensure compliance with ICs. In addition, ICs are typically incorporated into land use covenants (LUCs) recorded to the property deed. The LUCs are approved and executed by the Regional Water Board and the responsible party. The LUCs are publicly recorded in the county recorder’s office by the property owner. The Regional Water Board has an approved model Covenant and Environmental Restriction on Property that should be used when developing a site-specific LUC.

8. Document Submittal Content

This section presents recommended topics and content to be included in VIM-related documents, organized by document type.

8A. OM&M Funding Plan

The OM&M Funding Plan is typically required to demonstrate that sufficient funds are available to cover all OM&M costs anticipated for the operational lifetime of the VIMS. In some cases, the Regional Water Board may require that the Funding Plan includes a financial assurance mechanism (e.g., trust fund, surety bond, letter of credit, insurance, corporate guarantee, qualification as a self-insurer by a financial means test, or other acceptable mechanism). The Funding Plan should address the following:

- Responsible entity – Identification of the responsible entity and contact information

- Annual long-term costs – Estimate the annual cost of all VIMS related OM&M activities anticipated until the VIMS is decommissioned, considering the following typical elements:
    - Operation of the VIMS
    - Fees to hire an environmental consultant with the technical knowledge and ability to successfully implement the VIMS OM&M Plan (or monitoring-only plan for applicable buildings)
    - Materials and labor costs for (1) long-term maintenance, monitoring (inspections, sampling, analysis), and reporting and (2) shutdown and/or decommissioning
    - Fees for regulatory oversight cost recovery
- Funding source – Description of how the funds will be generated and managed
- Financial assurance mechanism (if required) – Identification of the selected mechanism (e.g., California Code of Regulations Title 27)

8B. VIMS Design Plan Content

A VIMS Design Plan presenting design details and describing the installation activities should be submitted for Regional Water Board review and approval before system installation commences. In general, the following topics should be addressed, though the level of detail will vary depending on site-specific conditions:

- Physical characteristics of the site, property boundaries, and other pertinent features
- Conceptual Site Model Summary – Summary of the nature and threat posed by the subsurface VFCs, geology, and groundwater conditions. Supporting tables and figures should be included.
- Remediation Status – Discussion of the status of remediation (e.g., whether feasible remediation has been completed, is ongoing, or is not warranted). For situations where feasible remediation has not been completed and is not proposed, an adequate justification should be provided.
- Building Design and Condition – Description of type and use of existing or future building, description of HVAC system and operation, existing building condition, and other information relevant for the VIMS. Drawings of the building layout and location of subsurface conduits/utilities should be included.
- Project Organization – Description of the roles and responsibilities and contact information for responsible entities (e.g., property owner, VIMS engineer, contractors), overseeing regulatory agencies, and interested parties
- Proposed System Design – The reason for the VIMS, performance objectives (e.g., allow occupancy while remediation is underway, protect occupants from

residual subsurface VFC contamination), description of system function and components, specifications, performance measures, and estimated operational lifetime of the VIMS. Useful figures typically include the following:

  - Base map showing the building(s), pertinent building features (e.g., rooms, vapor entry points in the building envelope, pathways to upper floors), and system components (e.g., monitoring points)
  - Maps that overlay historical sample locations and/or relevant subsurface VI data (e.g., soil gas, groundwater) to show the area(s) requiring mitigation onto the base map.

- Construction Methods – Description of construction (specifications, materials, installation procedures), coordination activities (e.g., notifications), and construction verification (inspections, testing).
- Passive Systems Designed for Conversion to Active Operation – Description of the elements to be installed (electrical outlets and connections) during system construction and elements to be installed later, if active operation is necessary (e.g., fan, telemetry system). Summary of the steps necessary for conversion including fan installation, permitting, startup, and the estimated schedule. Calculations to size the active system blower and demonstrate sufficient venting capacity should be included for all venting systems (passive and active).
- Post-Installation Baseline and Startup Sampling/Testing Procedures – Description of the post-installation baseline and startup sampling plan and any additional startup testing procedures.
- Performance Monitoring Plan – Description of the samples and measurements needed for performance monitoring, including:
  - Data quality objectives
  - Sample/measurement locations and rationale
  - Sample/measurement types, duration, collection/measurement procedures, HVAC operations during sampling
  - Laboratory analytical methods and detection limits
  - Data/information evaluation procedures
  - Monitoring schedule for baseline, startup, and long-term monitoring
- OM&M Overview – An overview of OM&M should be included in the Design Plan so that relevant components are identified, and future inspections and maintenance activities are understood. The OM&M Plan (described in Section 8C) typically is separately submitted, preferably after installation/construction so that as-built drawings and photographs can be included. The overview should describe the following:

    - Contingency actions – A description of contingency actions for situations where the VIMS is not operating properly and successfully (e.g., system failure, unfavorable monitoring results). See Section 8C for further information.
    - Activities and schedule for routine system checks and maintenance of components (e.g., mechanical, electrical)
    - Reporting
    - Shutdown/decommissioning processes
- OM&M Funding Plan summary – Brief description of the plan
- Public Participation – Description of the notification processes (pre-construction, during OM&M)
- Institutional Controls – Description of the plans and procedures that minimize exposure pathways or ensure the upkeep and effectiveness of the VIMS (e.g., access agreements, land use controls, management plan, enforcement mechanism).

8C. OM&M Plan or Monitoring Only Plan Content

Building with VIMS should have OM&M plans while buildings without VIMS should have a Monitoring Only Plan. Both types of plans should describe the VIM design and components, performance monitoring to demonstrate continued effectiveness, reporting requirements, and procedures for determining when VIM is no longer necessary. In addition, a VIMS OM&M plan should also describe VIMS startup activities and maintenance to be conducted on a routine and contingency basis. All plans should be amended as needed based on significant changes in VIMS operation and/or VIM effectiveness. The following elements should be addressed in a VIMS OM&M Plan or in a Monitoring Only Plan, as applicable.

- General Information
    - Background – Summary of information presented in the VIM Design Plan necessary to convey site characteristics, the need for mitigation, funding, and institutional controls that ensure continued effectiveness of system (e.g., LUCs, disclosure documents).
    - Project Organization – Description of the roles and responsibilities and contact information for responsible entities (e.g., property owner, VIMS engineer, contractors), overseeing regulatory agencies, and interested parties. The VIMS engineer should be familiar with the system operation, and either is or works under the guidance of a California licensed civil engineer.

  - Building Condition and Use – Description of system installation and modifications, HVAC system, and ventilation (windows, air intake, exhaust).
  - Description of VIM measures
  - VIMS Components – List of components and description of their purpose, type and function, materials, and expected operational life.
  - VIMS Related Permits
  - Communications Plan – Describes how building owners and occupants will be notified of any VIM related work and informed of monitoring results.
  - Appendices – System plans, equipment and material manuals and specifications, standard operation procedures (e.g., SAP for vapor/groundwater sampling), inspection forms and checklists, fact sheets.
- VIMS Operation Information
  - VIMS Construction and Startup – Summary of the construction and startup process, including a description of the baseline and startup sampling results. Include construction and startup procedures for any necessary system conversion between passive and active operational modes.
  - Expected Operational Lifetime of VIMS – Statement regarding how long the system is expected to operate without repair/replacement of components and identification of components most susceptible to breakage or degradation and anticipated timeframe for replacement/repair.
  - VIMS Physical Hazards – Description of the hazards associated with operating equipment, trip and fall, noise, electrical, and other health and safety aspects.
  - Routine VIMS Operation Procedures – Description of the procedures for planned or potential operational modes (i.e., for systems convertible to active, both passive and active operational modes are described) are provided.
  - VIMS Shutdown and Decommissioning – Description of the processes for shutdown of an active operating system (i.e., conversion from active to passive) and for decommissioning, which is determining when mitigation is no longer required by the Regional Water Board.
- VIMS Maintenance Information
  - VIMS Inspections and Maintenance – Procedures and frequency for observing system components to confirm the system is operating within the design parameters or operational range and correcting any identified issues. Includes description of temporary shutdowns for maintenance.

    Also includes verifying whether there have been changes in property ownership/status or the building condition/modifications and applicable notification procedures.
  - Inspections at Buildings without VIMS – Procedures and frequency for observing building condition and use to confirm no significant changes.
- VIMS Monitoring and Contingency Information
  - Monitoring – Identifies performance measurements, measurement objectives, and evaluation criteria, as described in Section 4. Identifies frequency of measurement and measurement procedures, as described in Attachment 1.
  - Contingency Plan – Describes potential and pre-planned response actions for situations when VIM measures are not effective or there are conditions that suggest VIM measures are not likely to be effective in the near future. For each situation, the OM&M Plan or Monitoring Only Plan should describe the assessment, notifications, and pre-planned or potential responses along with the responsible entity and timeframes. Contingency situations that should be described in the OM&M Plan include but are not limited to the following:
    - Power off (Active systems)
    - Unfavorable monitoring results – This could include vapor concentrations exceeding action levels or, for active systems, other test measures (fan vacuum, air flow, or subslab negative pressure/vacuum) being out of their documented operational ranges
    - Change in property ownership, building use or modifications (renovations, remodeling), building HVAC system
    - Evidence of incidental damage to or tampering with VIMS components
    - Catastrophic events that could damage building structures (e.g., earthquakes, fires)
  - Reporting – Summary of the content and schedule for long-term monitoring, five-year review, and incident reports.

8D. VIMS Construction Completion Report Content

The Construction Completion Report documents the VIMS installation and system startup, provides an evaluation of initial effectiveness, and documents baseline operating conditions. Recommended content includes:

- Background – Site description and summary of relevant findings/conditions during construction and startup

- VIMS – Purpose and description
- System Construction
- Preparation and Permits
- Summary of Construction and Installation
    - Description of site construction activities – Grading (area and depth), soil import, and utility installation. The grading and soil import information can be helpful in estimating time for soil gas to reach steady state conditions.
    - Description of building construction/modification activities – Documentation (drawings, photographs, product information sheets) of system component installation (e.g., venting layer, vapor barrier, piping, fan/blower, monitoring points), construction oversight, verification testing, and results. Discussion of issues encountered, modifications, and variances from the Design Plan.
    - Summary of Third-Party Certification (if performed) – Description of inspections and testing performed to ensure the system was installed and is operating in accordance with the Design Plan. The certification should be signed and stamped by a California licensed civil engineer.
- Drawings – As-built drawings of system components (e.g., overall site plan, plan/profile views of building foundation with system layout such as vapor barrier coverage, piping alignments, sampling probes). The drawings should be signed and stamped by a California licensed civil engineer with a statement that the VIMS was installed to the manufacturer's specifications.
- Post-Construction Inspection and Testing – Description of observations, procedures, results, and data evaluation.
- Baseline and Startup Performance Measurements – Description of procedures, results, and data evaluation.
- VIMS Effectiveness Evaluation
- Conclusion/Recommendation – Discussion of the results and recommendations for additional actions (if needed) and occupancy.
- Appendices – Copies of permits, field notes (inspections, measurements), photographs (system installation and completed system components), and laboratory analytical reports.

8E. Monitoring Report Content

Ongoing reporting serves the purpose of documenting that the VIMS or VIM by building design continue to successfully mitigate VI over time.

8E.1 General Content for All Monitoring Reports

Monitoring reports typically are submitted on a frequency consistent with the approved OM&M or Monitoring Only Plan and document the results of inspections, maintenance, and performance measurements. Recommended content includes:

- Introduction – Purpose of the report
- Activities – Description of the activities performed during the subject monitoring period including inspections, maintenance, and monitoring
- Results – Discussion of the system and/or building condition, presentation of the monitoring results, and evaluation whether the system and/or building is continuing to effectively mitigate VI
- Issues and Recommendations – Discussion of issues identified during the review and whether the issues affect current or future protectiveness. Present recommendations such as follow-up actions (e.g., system upgrade, optimization), responsible entity, and schedule for completion.
- Appendices – Copies of field notes (inspections, measurements), photographs, and laboratory analytical reports

8E.2 VI Screening Reports for Buildings without VIMS

The content of VI Screening Reports should generally include the following:

- Introduction – Purpose of the report
- Summary of CSM (e.g., land use, building use and condition, subsurface conditions, contaminant distribution)
- Activities – Description of the activities performed for the screening investigation
- Results – Discussion of observations and sampling results
- Data Evaluation – Evaluation whether VI is occurring, assessment of current and future VI risk
- Recommendations
- Appendices – Copies of field notes (inspections, measurements), photographs, and laboratory analytical reports

8E.3 First Year VIMS Monitoring Report

The first year VIMS monitoring report should include an evaluation of the system operation during the first year's monitoring over different seasons. Performance measurements during year 1 are described in Section 4. The report should identify the worst-case season (e.g., winter in many cases) for future sampling. If this differs from the OM&M Plan, an amendment to the latter may be warranted.

8E.4 VIMS Five-Year Review Reports

The purposes of a five-year review (FYR) are: (1) verify the VIM measures remains effective; (2) evaluate whether changes are needed; and (3) remind all project contacts (e.g., owner, occupants, VIMS engineer, regulatory agency) of the presence and need for the VIM measures. Evaluation of the VIM measures and the determination of protectiveness should be based on and sufficiently supported by data and observations. The report should include the following:

- Introduction – Purpose of the review, entity conducting the review, dates conducted, whether it is the first or subsequent FYR
- Site Characteristics – Summary of current physical characteristics, site conditions (e.g., current VI threat level), building condition and use, and property status. Any significant property or building changes during the preceding five-year period should be discussed. For current VI threat level, presentations of subsurface concentration data and trends in tables, maps, or graphs may be necessary.
- Project Organization – Identification of any changes to the contact information or persons identified as responsible in the OM&M or Monitoring Only Plan
- Five-Year Review Activities – Description of the activities performed for the review (e.g., review of previous inspection reports and data, site inspections, testing)
- Description of the system or building design (for monitoring only) as originally constructed (or at the time of the previous FYR) and discussion of any significant modifications during the preceding five-year period (e.g., change from passive to active operation, replacement/repair of primary components)
- Summary of VIMS operations and/or HVAC operations during the preceding five-year period
- Assessment – The report should address the following questions:
  - Does the remaining subsurface contamination still pose a VI threat?
  - Is the VIMS or building design functioning to effectively protect human health based on performance measurement results?
  - Are the performance measurement objectives and criteria aligned with current standards and screening levels?
  - Has any other information been discovered that raises uncertainty about whether the VIMS or building is protective?
  - Does the existing OM&M Plan or Monitoring Only Plan warrant an update or amendment?
  - Have there been technological, scientific, or equipment/material updates that would make the VIMS more efficient and effective?

    - Are the project contacts aware of the presence and need for VIM measures?
- Issues and Recommendations – Discussion of issues identified during the review and whether the issues affect current or future protectiveness. Present recommendations such as follow-up actions (e.g., system upgrade, change monitoring frequency), responsible entity, and schedule for completion.
- Appendices – Copies of field notes (inspections, measurements), photographs, and laboratory analytical reports

8E.5 VIMS Incident Reports

VIMS Incident Reports should be submitted to document situations where the VIMS was not operating properly and successfully, and the situation was corrected. The Regional Water Board recommends these reports be submitted within 30 days of problem correction. Recommended content includes:

- Incident – Discovery and description of the problem
- Contingency Action – Activities performed to correct the problem
- Notifications – Summary of who was notified
- Testing Results – Summary of any testing or sampling and analysis performed
- Conclusions and Recommendations

8F. Curtailment Workplan and Report Content

This section describes the processes and report submittals for curtailment, which is shutdown of an active VIMS (conversion to passive operation), decommissioning of a passive VIMS (determining that the passive VIMS is no longer needed), or final monitoring at buildings without VIM measures.

The curtailment process consists of evaluating whether available data and information indicate that conditions will likely be protective with the change, proposing and conducting a curtailment assessment, and then evaluating the data/information to determine whether the change will remain protective over time.

Section 4B.5 describes conditions when curtailment may be appropriate and recommended performance monitoring to support curtailment decisions.

8F.1 Workplans for Curtailment

Prior to curtailment, a workplan should be submitted to the Regional Water Board for review and approval that describes the data/information to be collected for the curtailment evaluation. The workplan should include the following:

- Justification – Description of the basis for curtailment that includes an evaluation of appropriate LOEs
- Notification Procedures – Description of the notifications to be provided to building owners and occupants
- Curtailment Procedures – Description of powering off and lock out/tag of the power source of an active VIMS, thus causing the VIMS to operate in a passive mode. Description of rendering the passive VIMS inoperable by preventing vapor exhaust to the atmosphere (e.g., capping the vent pipes, closing valves).
- Steady State Vapor Concentrations (Active VIMS only) – Estimation of the length of time for vapor concentrations to rebound and reach near steady-state (equilibrium) conditions beneath and inside the building following curtailment of active or passive VIMS (see Section 4B.2). For shutdown of an active VIMS, this information can be used to indicate the minimum period of time needed for long term monitoring of the passive VIMS (see Section 4B.3).
- Sampling Plan – The plan should describe the samples and measurements needed to demonstrate effectiveness and protectiveness. See Section 4B.5 and Tables 4 through 7 for details on curtailment performance measurements. The plan should include the following:
    - Data quality objectives
    - Sample/measurement locations and rationale
    - Sample/measurement types, duration, collection/measurement procedures, HVAC operations during sampling
    - Laboratory analytical methods and detection limits
- Restart Procedures – Summary of system restart or vent uncapping procedures to be implemented in the event sampling results indicate an unacceptable risk.
- Schedule
- Reporting – The results of the curtailment evaluation should be reported along with recommendations for the future VIMS mode of operation (if any) and any necessary amendments to the OM&M or Monitoring Only Plans.

8F.2 Reports of Curtailment

After the shutdown, decommissioning, or final VIM monitoring evaluations, a report should be submitted to document whether the process was successful (i.e., the testing results support shutdown, decommissioning, and/or final monitoring) and that the proposed updated VIM measures are protective. The report should include the following:

- Background – Site description and justification for the change in VIM

- Summary of the Verification Testing and Results
- Conclusions
- Next Steps – Notifications, amendment of the OM&M Plan (if needed)
- Appendices – Copies of field notes and laboratory analytical reports.

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10. Attachment 1: Sampling, Analysis, and Measurement Considerations for VI Evaluations

This attachment describes resources and information that should be considered when developing sampling and analysis plans. Recommendations are provided regarding collection and laboratory analysis of VFC concentration samples and subsurface to indoor air pressure differential measurements. The exact number and location of samples/measurements can vary for different stages of the VIM lifecycle. For example, fewer sampling/measurement locations may be needed during long term monitoring compared to initial baseline/startup and shutdown/decommissioning sampling events. See Section 4B for more information about sampling during specific stages of the VIM lifecycle at buildings with or without VIMS.

10A. Indoor Air Samples

Indoor air sampling data is the primary LOE when evaluating risk to current occupants because the data indicate the chemicals and concentrations to which occupants are directly exposed. VFCs in indoor air samples can be the result of subsurface vapor sources and/or other sources (e.g., ambient air, consumer products, building materials). Therefore, indoor air sampling results should be interpreted using multiple LOEs as described in Section 4B.1.a (Indoor Air Data Objective 1). This section focuses the collection of indoor air samples for risk assessment (i.e., the samples are collected at breathing height). The collection of indoor air samples for diagnostic evaluations is briefly discussed in 10A.5 (Vapor Entry Point Air Sampling).

10A.1 Building Survey

Prior to indoor air sampling workplan development, a building survey should be conducted to collect information to aid the design of the indoor air investigation. The overall objectives are to identify building use, building characteristics, and identify conditions that could affect indoor air or outdoor air sampling results. Information to be gathered includes the following:

- Building Use – Type (e.g., residential, commercial), periods and patterns/locations of building use, HVAC operation (e.g., windows/doors, HVAC systems, exhaust fans)
- Building Construction and Layout – Building age, foundation type and thickness, designed building use if different from current use, crawl space height, crawl space vent locations, room height, room and stairwell/elevator layout, number of floors.
- Ventilation/HVAC – Use of windows/doors, exhaust fans, and HVAC systems (including how the HVAC system functions regarding fresh air intake, location of air intakes, location of negative or positive pressurization zones, typical heating and cooling settings).

- Vapor Entry Points – Seams, cracks, floor drains, sumps, elevator shafts, openings to the subsurface
- Indoor Sources of VFCs – Typical sources include consumer products, household activities (e.g., smoking, attached garage), building materials and furnishings. List of products that potentially contain VFCs should be identified and inventoried (e.g., product, volume, location).
- Outdoor Sources of VFCs – Businesses or activities that could be a source of chemical emissions

As part of the building survey or prior to indoor air sampling, identify and remove potential indoor sources (e.g., cleaners, glues, fingernail polish remover, aerosol sprays, paint, and dry-cleaned clothes) provided the occupants allow removal. USEPA recommends removal of indoor sources 24 to 72 hours before a sampling event (USEPA 2015a). Not all indoor sources may be identifiable or removable.

Field Screening can be performed to identify indoor sources and vapor entry points. Field instruments that can detect low levels (e.g., parts per billion by volume detection limits) and speciate compounds are recommended over instruments that are less sensitive (e.g., parts per million by volume detection limits) or that only measure the total concentration of detectable VFCs. Alternatively, indoor air samples can be collected for laboratory analysis either at breathing height or at the height of potential vapor entry points (e.g., on the floor).

10A.2 Sample Location

Collect a sufficient number of indoor air samples per building to provide coverage across the building footprint, targeting these locations:

- Primary living/work areas (e.g., bedroom, living room, or office)
- Areas with slab/floor penetrations (e.g., bathroom, kitchen, or laundry room).
- Areas above suspected maximum subsurface contamination (e.g., near the center of the building, or known subsurface source).

For situations where the targeted locations are clustered in one area of a building due to the layout, additional locations should be sampled as needed for spatial coverage. The recommended number of sample pairs to provide adequate spatial coverage is three for a small building (less than or equal to 1,500 square feet) that has a single floor, has a single HVAC zone, and where the foundation is not segmented (e.g., grade beams). For large buildings, consider these additional sample locations:

- For large multi-unit structures, such as apartment buildings or strip malls, consider collecting at least one sample per ground floor unit.
- For buildings with foundations that segment the subsurface (e.g., grade beams), at least one sample should be collected in each separate area.

- For buildings with multiple HVAC zones, it may be appropriate to collect samples in each HVAC zone.
- For multistory buildings, sampling in occupied spaces on upper floors may be warranted in addition to sampling on the ground floor. Samples should be collected near conduits such as utilities, stairwells, or elevator shafts, that may provide a vapor pathway to the upper floors.
- If results of initial sampling show concentrations vary by more than an order of magnitude within a building; consider adding additional sample locations to evaluate the spatial distribution of VFCs.

Samples used for risk assessment should be collected at breathing height (e.g., 3 to 5 feet above the floor for adults).

10A.3 Sample Method

In general, indoor air samples should be collected in accordance with the VIG (DTSC 2011a), except for the locations and numbers of samples and sampling events described herein. The analyte list can be limited to the known or suspected subsurface VFCs assuming the subsurface contamination is well characterized and with agreement of the Regional Water Board. Field quality assurance/quality control (QA/QC) protocols for the collection of the indoor air samples should be consistent with the recommendations in the VIG concerning canister certification, field duplicates, and trip blanks. Laboratories should follow the QA/QC protocols in the USEPA analytical method regarding instrument calibration, holding times, recovery acceptance, and calibration verification.

Time-integrated samples are preferred for sampling indoor air to evaluate chronic exposures because time-integrated samples characterize the average daily inhalation exposure for building occupants. Typical sampling methods include:

- Conventional active sampling methods (e.g., canisters) typically have sampling durations of 24 hours for residential exposure and 8 hours for workplace exposure. However, longer duration samples (e.g., weeks) can be collected with canisters (ESTCP 2020).
- Passive sampling methods also are suitable for collecting time-integrated indoor air samples. Appropriate use of passive samplers requires knowledge of the target chemicals, sorbent capabilities, and required detection limits. Passive samplers may not be suitable for all chemicals of concern due to challenges posed by chemicals with weak sorption characteristics. Practitioners should confirm with the passive sample supplier that the available uptake rates and reporting limits for target VFCs are viable. This information should be documented in the building-specific sampling plan. Detailed information on passive samplers is presented in *Engineering Issue: Passive Samplers for*

Investigations of Air Quality: Method Description, Implementation, and Comparison to Alternative Sampling Methods (USEPA 2014b).

10A.4 HVAC Operations During Indoor Air Sampling

This section discusses HVAC operations during indoor air sampling. The way that a building is heated, ventilated, and/or cooled when occupied (i.e., typical use conditions) should be identified and documented during the building survey. The normal HVAC condition/operation for the season and time of day should be determined for windows/doors, HVAC systems, and exhaust fans.

Indoor air sampling generally should be performed under typical HVAC operations to evaluate current risk. During the sampling, ingress and egress should be minimized to the extent feasible. For sampling during colder months, heating systems should be operating for at least 24 hours prior to the scheduled sampling event to maintain normal indoor temperatures above 65°F before and during sampling.

In addition to sampling during typical HVAC operation conditions, indoor air sampling under alternative conditions can be important for diagnostic purposes. Alternative HVAC operation conditions should generally be safe for occupancy, even if the building is not occupied at the time of sampling.

An example of indoor air sampling under alternative conditions is HVAC-On/HVAC-Off Sampling, which is performed to evaluate how a building's HVAC influences VI and the potential risk if HVAC use changes in the future. HVAC On/Off sampling typically consists of indoor air sampling performed with HVAC-On followed by indoor air sampling with HVAC-Off as described in the following section (Diagnostic Air Sampling).

10A.5 Diagnostic Air Sampling

Diagnostic air sampling refers to air samples collected to understand whether or how VI is occurring. These samples can be indoor air samples or other types of air samples. Examples of diagnostic air sampling include:

- HVAC-On/Off Sampling – These indoor air samples are collected to evaluate the effects of HVAC operation on VI while mitigation measures are operational. During a single event, sampling is performed during two periods: one period with the HVAC-On and one period with the HVAC-Off. This captures a range of possible conditions and resulting risk to occupants if HVAC use changes. If possible, this evaluation should be conducted when HVAC activities are most likely to increase VI as determined by building specific conditions and operations. For HVAC-On conditions, the typical heating, cooling, and/or ventilation activities for the season should be operational (e.g., HVAC system cycling on and off normally, open windows, open warehouse garage doors, exhaust fan on) for 36 hours prior to sampling. HVAC-Off conditions can include non-operation of an HVAC system or fans and/or closed doors and windows. For the HVAC-Off scenario, the sampling duration should begin with closed doors and windows at least 36 hours following shutdown of fans and the HVAC system (no outdoor air intake into the building) and continue while HVAC systems remain off (USEPA 2013). HVAC-Off sampling should only be conducted when it is safe and feasible to do so.

- Indoor Source Characterization Sampling – These air samples are collected to evaluate VFC air concentrations in the vicinity of specific materials or products.
- Pathway Sampling – These air samples are collected to evaluate whether and how VFCs are being transported through a building (e.g., stairwells to upper floors).
- Vapor Conduit Sampling – These air samples are collected to evaluate whether VFCs are potentially being transported into indoor air via vapor conduits (e.g., sewer pipe, utility conduits).
- Vapor Entry Point Sampling – These air samples are collected to evaluate whether VFCs are entering through a particular feature (e.g., crack, sump, elevator shaft, rooms with exhaust fans) and to help interpret other indoor air results. Typically, these samples are collected close to the feature rather than at breathing height (e.g., on the floor for foundation cracks).

10B. Subslab Soil Gas Samples

Subslab soil gas (subslab) samples are vapor samples collected beneath the foundation of slab-on-grade buildings. Subslab sampling results are used for characterizing the presence and concentrations of VFCs immediately below a building that can migrate into indoor air. For crawl space buildings with a membrane (vapor barrier) installed on the ground surface, samples collected from beneath the membrane may be considered similar to subslab soil gas.

Exterior, near-source soil gas sampling may be used as a surrogate for subslab sampling on a site-specific basis (e.g., the building was constructed without subslab sampling ports). However, exterior soil gas is unlikely to be representative of the concentration below the slab if the release occurred within or just below the building footprint.

10B.1 Sample Location

A subslab sample generally should be paired with each indoor air sample location discussed above. If there are potential stagnation areas within the venting layer of a VIMS, additional subslab samples should be considered. In general, all sample locations should be about midway between vent pipes and away from any ambient air inlets or building edges (see Section 3A.5).

10B.2 Sample Method

Subslab samples should be collected in accordance with the Active Soil Gas Investigations Advisory (CalEPA 2015). These samples typically are grab samples collected from permanent installations (see Section 3A.5). When sampling concurrently with indoor air, subslab samples should be collected soon after indoor air (e.g., within 8 to 24 hours) to avoid cross-contamination of indoor air samples from VFCs released during purging and sampling. Alternatively, if subslab samples must be collected before indoor air sampling, allow sufficient time for subsurface VFCs released into indoor air during subslab sampling to dissipate (generally 24 to 72 hours; USEPA 2015a).

10C. Outdoor Air Samples

In the context of vapor intrusion, outdoor air sampling results are used to determine potential influences of outdoor air contamination on indoor air quality, thus aiding with indoor air data interpretation and determining VI contribution.

10C.1 Sample Location

Sufficient outdoor air samples should be collected to achieve both performance measurement objectives:

- Support Indoor Air Data Interpretation – Outdoor air sample locations should be determined considering the following:
- Location/Height – Outdoor air samples should be collected on the upwind side of the building at a distance equal to twice the height of the building and at approximately six feet above the ground surface.
- Avoidance of Localized Outdoor Sources – Outdoor air sample locations should not be placed in the vicinity of localized outdoor sources (e.g., gasoline stations, gasoline-powered engines, chemical storage areas, dry cleaners, and remediation or mitigation systems).
- Avoidance of Subsurface Source Influences – In addition, outdoor air samples should be placed where influences from subsurface sources are minimized (e.g., where outdoor air is not directly influenced by the release, and far from vent pipes). If subsurface VFCs are emitting to outdoor air at measurable concentrations, outdoor air results should not be considered ambient background. The results of samples placed near localized subsurface sources could promote an incorrect conclusion that outdoor source(s) are present.
- Evaluate Re-entrainment – Outdoor air samples should be collected at or near VIMS discharge locations.

10C.2 Sample Method

Outdoor air samples should be collected using the same method as the indoor air samples, as described above. USEPA generally recommends beginning ambient air sampling at least one hour before indoor air monitoring begins, but preferably two hours, and continuing to sample until at least 30 minutes before indoor monitoring is complete (USEPA 2015a). This practice is recommended because most residential buildings have an air exchange rate in the range of 0.25 to 1.0 exchanges per hour. Recommended lag times may need to be adjusted for nonresidential buildings with different air exchange rates (e.g., lag times may be shorter if the expected indoor air exchange rate is higher for a nonresidential building). If the subsurface contamination is well characterized, the analyte list may be limited to the indoor air analyte list.

10D. Vent Riser Air Samples

Vent riser air samples are air samples collected from inside a VIMS riser pipe. The objective of vent riser air sampling is to determine whether VFC concentrations exceed air permit standards and therefore require treatment before discharge to outdoor air.

10D.1 Sample Location

The samples should be collected from all vent risers at accessible locations (e.g., sample ports).

10D.2 Sample Method

Vent riser air samples should be collected using the same method selected for indoor air sampling, as described above.

10E. Crawl Space Air Samples

Crawl space air samples are a type of pathway air sample collected from a crawl space, which typically is a short, unoccupied space beneath buildings with a raised foundation such that it is not possible to stand up. Crawl space air sampling results are used to determine VFC concentrations that may enter a building from the underlying crawl space and degrade indoor air quality.

10E.1 Sample Location

The overall number and location of crawl space air samples should provide adequate building coverage, with a minimum of two samples for a small building (less than or equal to 1,500 square feet) (see considerations for large buildings in Section 10B.1) above). The crawl space air sampling design should consider the following locations:

- Areas away from exterior vents to outdoor air and extraction locations where there is a potential for air stagnation

- Near suspected maximum subsurface contamination
- Near emergent subsurface utilities
- Areas directly below indoor air sample locations

10E.2 Sample Method

Crawl space air samples should be collected using the same method selected for indoor air sampling.

10F. Near-Source Soil Gas Samples

Near-source soil gas sampling results are used for characterizing VFCs emitted into soil gas from subsurface vapor sources in soil and groundwater to assess subsurface vapor source strength over time for VI risk evaluations. This data can be used to demonstrate concentration trends and support site-specific soil gas attenuation through the vadose zone which are important LOEs used to inform VIMS shutdown and decommissioning decisions.

For sites where petroleum VFCs are COPCs, soil gas samples typically should be additionally analyzed for fixed gases (e.g., oxygen, carbon dioxide, methane) to support the evaluation whether biodegradation is occurring to a sufficient degree. This can allow for use of a BAF as described in ESL User's Guide Section 5.4.4.

10F.1 Sample Location

Near-source soil gas samples should be collected from enough locations to achieve the performance measurement objective: assess subsurface vapor source strength over time for future VI risk assessments. These soil gas samples should be collected between the building and the nearest vapor source (i.e., release area or downgradient groundwater plume), laterally as close as possible to the building (or beneath if possible). Near-source soil gas samples should be collected from a depth just above the nearest subsurface vapor source, unless the source is deep (e.g., greater than 20 feet below ground surface). For deep vapor sources (e.g., groundwater), near-source soil gas samples should be collected at a depth of 15 feet below the foundation. Further information is presented in ESL User's Guide Section 5.1.1 (Regional Water Board 2019b), including a discussion of the slab capping effect.

10F.2 Sample Method

Near-source soil gas samples should be collected in accordance with the Active Soil Gas Investigations Advisory (CalEPA 2015). These samples are typically grab samples.

10G. Groundwater Samples

Groundwater sampling results are used for characterizing VFCs in groundwater that can potentially be emitted into soil gas that could migrate into indoor air. This data can be used to demonstrate concentration trends which are an important LOEs used to inform VIMS shutdown and decommissioning decisions.

Sample Location: Groundwater samples should be collected from enough locations to achieve the performance measurement objective: assess subsurface vapor source strength over time for future VI risk assessments. Groundwater data should be used from the monitoring well located closest to the building, on the side of the building where concentrations are expected to be highest. Groundwater samples for VI evaluations should be collected over a narrow interval just below the water table or first groundwater where feasible (USEPA 2015a; DTSC 2011a). VFC diffusion through water is about four orders of magnitude slower than diffusion through air—therefore VFC concentrations at deeper depths within the groundwater column typically have less relevance for VI evaluations.

Sample Method: Groundwater samples generally should be collected in accordance with the Guidelines for Planning and Implementing Groundwater Characterization of Contaminated Sites (DTSC 2012b). Additional information is provided in Well Design and Construction for Monitoring Groundwater at Contaminated Sites (DTSC 2014).

10H. Subsurface to Indoor Air Pressure Differential Measurements

This section focuses on subsurface to indoor air pressure differential ($\Delta P_{SS\text{-}IA}$) measurements collected to determine whether the venting layer is depressurized relative to a building's interior for depressurization VIMS. However, $\Delta P_{SS\text{-}IA}$ measurements may also be used to support VI evaluations at buildings with ventilation VIMS or buildings without VIMS.

Measurement Location: $\Delta P_{SS\text{-}IA}$ measurements should be collected from enough locations to meet the objective of confirming that VI is not occurring for VI risk assessments. These measurements should be collected from subslab vapor probes/ports installed about midway between collection pipes, and away from building edges. Ideally these ports should be installed through the slab such that the probe/port allows measurement of both the subslab and indoor air pressures. Alternatively, $\Delta P_{SS\text{-}IA}$ can be calculated from measurements at two probes: (1) a subslab probe installed beneath the foundation that allows only subslab pressure measurement; (2) a probe installed indoor that allows only indoor air pressure measurement provided that the frictional losses of the tubing for each probe are about the same.

Measurement Method: $\Delta P_{SS\text{-}IA}$ typically is measured using micromanometers with pressure transducers and dataloggers installed at subslab probes. For situations where subslab samples are to be collected for laboratory analysis during the same mobilization that $\Delta P_{SS\text{-}IA}$ will be measured, the $\Delta P_{SS\text{-}IA}$ should be measured first because the purging and sampling of subslab probes could cause pressure disruptions. Similarly, indoor air sampling should be performed before either the $\Delta P_{SS\text{-}IA}$ measurements or subslab probe sampling if those activities could release subsurface VFCs into indoor air.

11. Attachment 2: Lines of Evidence for VI Evaluations

Lines of evidence are qualitative or quantitative information used to develop the conceptual site model (CSM) and support VI pathway evaluations. Lines of evidence (LOEs) can be diverse types of information, such as indoor air sampling data, subsurface sampling data, site history information, building condition, field instrument results, soil type, contaminant subsurface source type and strength, and results of mathematical modeling.

Using multiple LOEs provides a more comprehensive understanding of vapor intrusion (VI) at a site and increases confidence in assessing and managing potential health risks from the VI pathway. Multiple LOEs should be used to reduce the overall uncertainty when considerable uncertainty is associated with one or more individual LOEs.

Each LOE should be weighted (i.e., assigned importance) based on the following and the site characteristics:

- Relevance – Degree of correspondence between the evidence and the assessment endpoint to which it is applied
- Representativeness – Correlation evident between a sample of a population and the population from which it is taken. For a media sample, this means the sample reflects the targeted medium.
- Quality – The extent to which a product meets specifications. For example, a media sample collected according to an acceptable protocol, or a laboratory analysis performed according to a particular method.

An LOE may be weighted differently for another site, a different building at the same site, other scenarios for the same building (e.g., changes in condition, operation, or use), or for separate sampling events.

After each LOE is weighted, the available LOEs should be weighed (i.e., integrated and interpreted) in the multiple LOEs approach. It is not uncommon that all LOEs may not be in concordance. Ambiguous or discordant LOEs should be evaluated and explained rather than dismissed. The CSM should be revised with the collection of updated information and/or new LOEs. The evaluation of LOEs may be more or less formal depending on the complexity of the CSM. Further information regarding the application of multiple LOEs (also referred to as “weight of evidence”) is provided by USEPA (2015).

Typical LOEs used for developing the CSM and evaluating VI are summarized in the subsections below along with some less commonly used methods.

11A. Site Characterization

In general, the better a site is characterized, the less uncertainty is associated with the risk assessment, and the less conservative risk management decisions can be to ensure protection of human health. At sites with limited empirical data on site specific conditions, the assumptions that are made to compensate for limited data need to be conservative enough to balance the possibility that the available information may lead to underestimating the risk to human health.

11B. Site History

The more that is known about the site history, operations, chemical use, and potential release locations and mechanisms, the less uncertainty the CSM will have and, hence, the less uncertain VI exposure estimates will be. Site history is important for many aspects of VI evaluations, from designing investigations to interpreting data. For example, knowledge of site history may help attribute the presence of a particular vapor forming chemicals (VFC) in indoor air to past site uses, rather than current indoor or outdoor sources.

11C. Building Characteristics

A unique aspect of evaluating the VI pathway compared to other exposure pathways is the dynamic role of the built environment. A building’s construction, condition, and use affect the migration (i.e., "intrusion") of contaminant vapors from the subsurface into indoor air, air mixing and exchange, and the resulting indoor air concentrations of VFCs. Additionally, changes in these factors over time can increase or decrease the potential for VI. Building characteristics important for evaluating VI include:

11C.1 Building Design and Construction

Buildings have different characteristics based on the design type. The following types of buildings are listed in order from those generally most susceptible to those least susceptible to VI considering surface area in contact with soil and degree of openness to outdoor air: dirt floor basement, slab on grade, crawl space, subterranean ventilated garage, open air garage, and podium construction. No building should be considered inherently safe. Features that penetrate the building envelope (e.g., elevator shafts, sumps, utility conduits) may render any building more susceptible to VI. This should be considered when selecting the media and locations to sample as well as remedial and mitigation options that are viable for the specific building.

11C.2 Building Condition

A building’s condition can change over time due to deterioration of building materials, renovations, cracking/settling, or catastrophic events (e.g., earthquakes). If building design and construction are used to support risk management decisions, then monitoring the building condition over time is warranted to evaluate whether the assumptions continue to be applicable and protective (e.g., during operation and maintenance inspections or as part of five-year reviews).

11C.3 Building Ventilation

The way buildings are heated or cooled can greatly influence the potential for VI. Heating, ventilation, and air conditioning (HVAC) systems include heaters, fans, mechanical vents, and air conditioners. Operable windows and doors provide natural ventilation. Exhaust fans can locally depressurize a building's interior (e.g., bathroom, kitchen). The systems for each building should be identified and evaluated. HVAC systems are dynamic, frequently turning on and off, changing diurnally and seasonally, and may be reconfigured based on changes in building use or occupant preference. This variation should be considered when planning and conducting sampling, evaluating results, and making risk management decisions.

11D. Subsurface Conditions

Subsurface conditions can significantly influence the potential for VI where the subsurface source of contamination is not in contact with the building foundation. In these situations, vapors must migrate toward the building through porous media or via preferential pathways. Primary factors influencing soil gas as the transport medium for vapor phase contaminants are described herein.

11D.1 Geology and Stratigraphy

The soil type and conditions beneath the building are important factors that influence soil gas flux and the design of effective VIMS. Site soil types and subsurface conditions can significantly influence the potential for VI. The transport of soil gas in the vadose zone is dominated by diffusion with advection only occurring in the immediate vicinity of buildings or when there is a pressure gradient (e.g., landfills) (USEPA 2012a). Diffusion occurs from areas of higher concentration to areas with lower concentrations. Air-phase diffusion is about 10,000-times greater than water-phase diffusion. Vapor-phase diffusion in the subsurface varies with total porosity and moisture content (i.e., how much of that total porosity is water filled). Soils with high moisture contents limit air diffusion by cutting off air-filled pores and making diffusion through water the primary transport mechanism. Fine-grained soils tend to have greater water-filled porosity than coarse-grained soils in the unsaturated under similar conditions. The presence of continuous, wet, fine-grained soil layers can significantly limit the potential for VI.

Conditions in the vadose zone and soil gas VFC concentrations be changed by construction of a new building and/or supporting infrastructure (USEPA 2015a). Construction activities and site changes may result in significant changes in the subsurface moisture profile. While moisture conditioning for soil compaction may temporarily increase moisture content, building/hardscape construction decreases soil moisture content beneath the hardscape thereby enhancing VFC migration in soil gas. Utility corridors may modify the vertical and horizontal distribution of soil gas VFC concentrations. Accordingly, as site conditions change, other LOEs may change, especially subslab and deeper soil gas VFC concentrations.

11D.2 Groundwater Conditions

When groundwater contamination is the vapor source, important considerations include location of the water table relative to the building foundation, VFC transport through groundwater, fluctuations of the water table (e.g., seasonal, periods of drought, sea level rise, tidal), and representativeness of groundwater samples for evaluating the VI pathway. For situations where groundwater is in contact with the building foundation and can potentially infiltrate a building, the VI potential is greater through direct emissions of VFCs into indoor air from groundwater (e.g., equilibrium partitioning using Henry’s law predicts that 5 micrograms per liter (µg/L) of PCE in groundwater corresponds to 3,600 micrograms per cubic meter (µg/m^3) PCE vapor above the water).

Groundwater samples collected near the water table are recommended to support VI evaluations (USEPA 2015a). To reach a building, VFCs in a groundwater plume would have to migrate upward through overlying water and then the capillary fringe. Away from the release area, the overlying water is the result of infiltrating precipitation or irrigation or leakage from pipes. Such recharge water likely is relatively clean. The capillary fringe is a transitional area of high soil moisture content at the base of the vadose zone above the water table. Chemicals migrate through water at a diffusion rate that is about four orders of magnitude less than the diffusion rate through air. Therefore, clean recharge and capillary fringe water above a groundwater plume are capable of significantly attenuating VFC vapors (McCarthy and Johnson 1993; USEPA 2012a). In that case, deeper groundwater samples would overestimate the VI risk.

Changes in groundwater levels can impact VI risk. For example, the capillary fringe can become contaminated due to water table fluctuations and therefore increase VI risk. In addition, declining water tables may leave residual vadose zone contamination that can readily partition into the vapor (gas) phase and more readily migrate (i.e., diffuse through soil gas rather than water).

11D.3 Preferential Pathways/Conduits

Subsurface drains and utility conduits can facilitate migration of vapor through the pipe itself and through more permeable backfill material. The presence of preferential pathways and their significance are not easily discerned by simple observation, review of building drawings, or traditional site characterization methods. Where conduits such as sewer lines intersect contaminated media, exterior soil gas sampling may underpredict the potential for VI. For guidance regarding the evaluation of the vapor conduit pathway, see ESL User’s Guide Section 5.4.1 and ESTCP 2018b, 2018c, and 2018d.

11E. Site VFC Contamination Characterization

In general, the better the nature and distribution of contamination is characterized, the less uncertainty is associated with the VI health risk assessment and the more confidence is increased that management decisions are protective of human health. At sites with limited empirical data on the nature and distribution of contamination, conservative assumptions are needed to compensate for the uncertainty and the possibility that limited available information may lead to underestimating current and potential future risk.

For characterizing contaminant distribution as part of VI evaluations, the primary LOEs are VFC concentration data from various media. Indoor air sampling data are the preferred LOE for assessing current risks for building occupants because indoor air data represent the VFC concentrations at point of exposure. Indoor air data should be supported by other LOEs (e.g., subsurface data, building construction and condition, preferential migration pathways, building survey, ventilation/HVAC operation, outdoor air data). Subsurface data are preferred for estimating potential future risks, supported by additional LOEs (e.g., subsurface source type/strength, depth and lateral location relative to buildings, site stratigraphy, soil properties, depth to groundwater, plume stability). Typical LOEs for characterizing VFC concentrations and distribution, presented herein, are divided into two categories, air and subsurface data.

11E.1 Indoor Air

Indoor air sampling results are the primary LOE when evaluating risk to current occupants because they indicate the chemicals and concentrations to which occupants are directly exposed. Indoor air data can represent a composite of VFCs from subsurface contamination and other potential sources: migration from subsurface sources through small openings in the foundation or vapor conduits, indoor sources, and outdoor sources. Interpretation of indoor air results requires consideration of supporting LOEs to characterize indoor air VFCs from sources other than or in addition to subsurface contamination.

11E.2 Outdoor Air

Outdoor air sampling results are used to determine potential influences of outdoor air contamination on indoor air quality, thus aiding with indoor air data interpretation and determining VI contribution. If there are detections of VFCs in the outdoor air data, regional ambient air data, such as the California Air Resources Board’s online database (https://www.arb.ca.gov/adam/toxics/toxics.html) may be used to gain insight into the likelihood that VFCs detected in outdoor air are due to regional background conditions.

11E.3 Crawl Space Air

Crawl space air sampling results are used to determine VFC concentrations and distribution that may enter a building and degrade indoor air quality. VFCs in crawl space air samples can be the result of subsurface, indoor and/or outdoor sources and therefore require supporting LOEs for data interpretation.

11E.4 Subslab Soil Gas

Subslab soil gas sampling results are used for characterizing the presence and concentrations of VFCs immediately below a building that can migrate into indoor air. Many state guidance documents consider subslab soil gas data as the best subsurface indicator of potential indoor air contamination from VI because the subslab location is within the advective influence of the building and the uncertainty associated with attenuation from the subsurface source to the subslab is not a factor. Near-source soil gas data are typically considered a conservative surrogate for subslab soil gas data.

11E.5 Soil Gas

Soil gas sampling results are used for characterizing VFCs emitted into soil gas from subsurface sources in soil and groundwater are the preferred subsurface data LOE over groundwater or soil matrix data. Near-source soil gas data are generally preferred over shallow exterior soil gas data (e.g., 5 feet or less bgs) because the latter is: (1) typically not representative of subslab soil gas concentrations where the subsurface vapor source is immediately below the building; (2) unlikely to be representative of future vadose zone conditions after development activities or subslab soil gas concentrations where the subsurface vapor source underlies an existing building; and (3) potentially subject to dilution by ambient air.

11E.6 Soil Matrix

In general, soil matrix sampling results should not be used for evaluating the VI pathway because of the uncertainty associated with estimating VFC partitioning to soil gas, and the potential loss of volatiles during sample collection, preservation, and analysis (DTSC 2011b; USEPA 2014a, USEPA 2015a). Soil matrix data is an important line of evidence for characterizing the release area (i.e., high concentrations, non-aqueous phase liquid). Soil concentrations and estimates of total mass and contaminated volume of soil are important factors in characterizing subsurface source strength and stability of soil gas concentrations (and potential VI) over time (see Source Type and Strength, below). Soil matrix data is also useful when evaluating potential remedies.

Soil samples for VFC analysis should be collected using USEPA Method 5035 for field preservation (e.g., low headspace sample containers, methanol preservation) (DTSC 2004). Results of samples collected without proper field preservation can have significant low bias, potentially up to 90 percent VFC loss (Hewitt 1994; Grant et al. 1996; Hewitt and Lukash 1996). USEPA Method 5035 was first implemented in 1997 though the method use likely was inconsistent in California until after 2005, following state sampling guidance. Historically, soil matrix data were routinely used for evaluating VI. Hence, caution should be exercised when evaluating soil matrix data, especially older results.

11E.7 Groundwater

In general, groundwater sampling results can be used as a supporting LOE to evaluate VI potential, with caution. Reliance on groundwater data for VI evaluation is not preferred due to uncertainty in predicting VFC partitioning from groundwater to soil gas and transport through the capillary fringe.

11E.8 Vapor Conduit Air

Vapor conduit air sampling is recommended as a supporting LOE to evaluate whether the conduit is a preferential pathway to indoor air. Characterization of VFCs the airspace of conduits aids interpretation of indoor air data.

11E.9 Field Instrument Measurements

Field instruments such as photoionization and flame ionization detectors typically are employed during the building survey prior to indoor air sampling to identify vapor entry points and locate potential indoor sources of VFCs. Field instruments may also be used to test vapor conduit air before sampling. Field instrument measurements are a supporting LOE and not a substitute for analysis using USEPA analytical methods (e.g., Method TO-15).

11F. Contamination Characteristics

The nature, magnitude, and distribution of contamination are critical to understanding the potential for VI. Factors to consider include the following:

11F.1 Source Type and Strength

Sites contaminated with non-aqueous phase liquid (NAPL) typically present a greater VI potential than sites with only dissolved-phase contamination. Subsurface source concentrations are typically much higher for NAPL sources than for dissolved-phase subsurface sources, leading to greater rates of mass diffusion (USEPA 2015b). This greater rate of mass diffusion can be persistent because NAPL subsurface sources contain significantly greater mass than dissolved-phase subsurface sources for a given volume.

11F.2 Contaminant Chemical/Physical Properties

Chemical/physical properties such as vapor pressure and the Henry’s Law Constant control the partitioning of individual VFC between phases (i.e., free phase, dissolved, sorbed, vapor) and migration potential and may be significantly different for each chemical. Vapor pressure is a measure of a chemical’s tendency to volatilize from the pure phase whereas the Henry’s Law Constant is a measure of the tendency of a chemical dissolved in water to volatilize. Chemicals of similar size can have significantly different partitioning characteristics. For example, naphthalene and TCE have similar molecular weights yet TCE's Henry's Law Constant is about 20 times greater than naphthalene indicating a greater propensity to volatilize from the dissolved phase. To minimize uncertainty in predicting partitioning, soil gas sampling results are the preferred subsurface data LOE over groundwater data.

Some VFCs may undergo chemical transformation while in storage or after release to the environment. While most chlorinated VFCs are relatively persistent in the environment, some chemicals (e.g., petroleum hydrocarbons) are much less persistent due to their susceptibility to biodegradation. Petroleum hydrocarbon vapor concentrations can decrease by orders of magnitude over short vertical migration distances in the presence of oxygen and under a wide range of conditions (USEPA 2012b). Chlorinated ethenes (e.g., tetrachloroethene, TCE) can biodegrade under reducing conditions. Vinyl chloride can also biodegrade in the subsurface under aerobic conditions (Patterson et al. 2013). The presence of co-contamination by multiple VFCs and semi- and non-volatile organic compounds, including petroleum hydrocarbons, may affect VFC fate and transport and is another important consideration.

11F.3 Vapor Transport Mechanisms

Vapor transport includes VFCs migration in soil gas through subsurface porous media or preferential pathway air toward the building, vapor entry into the building, and mixing with indoor air. Overall, vapor transport in the subsurface is controlled by contaminant partitioning (groundwater or soil moisture to soil gas), diffusion (transport from high to low concentration), and advection (transport from high to low pressure) (USEPA 2012a).

11F.4 Contaminant Distribution Relative to Buildings

The depth and lateral distance of the subsurface source from existing or future buildings are important factors in the potential for VI. For a given subsurface source type (e.g., soil or groundwater contamination) and strength, the potential for VI is greater where the contamination is close to the building and covers more of the building footprint. The VI potential decreases with increasing lateral distance and depth and less coverage of the building footprint.

11F.5 Contaminant Distribution Stability

Contaminant distribution, both in soil gas and groundwater, that has not reached steady-state conditions should be evaluated with caution and conservativism. Risk assessments based on current conditions may underestimate future risks if contaminant distribution is not stable (near steady state) and future subsurface concentrations increase near a particular building. See also Subsurface Conditions, above, regarding changes in contaminant distribution induced by site development.

11G. Weather/Meteorological Conditions

Aboveground environmental factors influencing spatial and temporal variability in VI consist of weather phenomena such as barometric pressure, temperature, and wind. These factors can also influence surficial soils. For instance, evaporation can enhance the removal of VFCs from surface soils (Yu 1994). These factors should be considered in determining when and where to sample, and in interpreting results.

11G.1 Barometric Pressure

Barometric pressure can influence soil gas concentrations during large barometric pressure cycles and can also influence the transport of soil gas into buildings (Massmann and Farrier 1992; Robinson and Sextro 1997; Robinson et al. 1997a, b). High barometric pressure (relative to the subsurface) can cause fresh air to migrate several meters into permeable soils thus lowering soil gas VFC concentrations. Conversely lower pressure relative to the subsurface may increase shallow soil gas VFC concentrations as vapors move upward from deeper subsurface sources. The greatest variability is expected during periods of rising or falling barometric pressure. Indoor-to-subsurface pressure differences similarly can influence the potential for VI. During high barometric pressure periods, VI may be reduced or eliminated as the building is pressurized relative to the subsurface, while during low barometric pressure periods, VI may be enhanced.

11G.2 Temperature Effects

Temperature differences between indoor air and the subsurface can result in convection driven by heated air that rises to upper levels of a building and leaks through roofs and upper-floor windows. The lower pressure of warm indoor air causes advective flow of soil gas from the subsurface through cracks and other openings in the foundation. The stack effect can be strongest during the colder weather when building interiors are heated or, potentially, on sunny days due to increased temperature of the roof and highest enclosed spaces.

11G.3 Wind Effects

Wind effects on VI are caused by differences in interior building pressure resulting from wind on a building's surfaces. The indoor air pressure will be higher on the windward side of the building than on the leeward side. This situation results in ambient air infiltration into the building on the windward site and indoor air exfiltration from the building on the leeward side. Wind loads on the ground surrounding buildings can also affect the subslab distribution of VFCs and contribute to spatial and temporal variability (Luo et al. 2009; USEPA 2012a). Given that wind direction is likely to vary, the effect may not be significant except potentially in regions where directional winds are consistent (e.g., coastal region afternoon onshore breezes).

11H. Other Vapor Intrusion Characterization or Evaluation Methods

Advancements in development of methods and technologies for characterizing VFC contamination at sites and evaluating VI are ongoing. Many of these methods are not routine or common. Hence, a work plan describing the proposed method and procedures along with justification should be submitted to the overseeing regulatory agency for review and input. Several of these methods are summarized below.

11H.1 Continuous Monitoring

This method consists of repeatedly measuring VFC concentrations (e.g., indoor air, subslab, outdoor air) and potential indicators of VI (e.g., barometric pressure, cross-slab pressure differential, and temperature) at frequencies of minutes to hours over the duration of a field investigation (Hosangadi et al. 2017; Kram et al. 2020), typically one or two days. Instruments may be configured to generate time series trends from multiple locations for several parameters. The data may be used to estimate VI risk and identify potential VI pathways and indoor sources. At this time, there is no guidance or standards regarding use of the method. Hence, for risk assessment, the results should be confirmed with the method described in Attachment 1. Continuous monitoring has been typically used after initial identification of elevated indoor air detections to help diagnose VI.

11H.2 Controlled Pressure Method

This method can be used to evaluate a building's susceptibility to VI during a brief field investigation of a few days (McHugh et al. 2012; Lutes et al. 2019; Guo et al. 2020; ESTCP 2021). The method involves two testing regimes, one under negative pressure conditions and one under positive pressure conditions. The pressure conditions are artificially induced using high flow fans. Indoor air VFC concentrations are measured over time during each testing regime. The negative pressure regime induces VI and may allow estimation of the upper end of indoor air concentrations under the current building condition while the positive pressure regime suppresses VI and can be helpful in identifying indoor sources of the target VFCs. The method has been suggested as an alternative to seasonal monitoring and could potentially be used to estimate building-specific AFs. Although recent test guidelines have been published (ESTCP 2021), current regulatory guidance does not explain how to appropriately implement and interpret CPM.

11H.3 High Purge Volume Subslab Sampling

The method consists of extracting a large (e.g., over 500 liters) volume of soil gas from beneath a foundation to provide spatially averaged concentrations for larger areas rather than more highly variable data resulting from discrete sampling of smaller volumes of soil gas. Sampling a large, extracted volume of soil gas potentially reduces the possibility of missing an area of elevated concentrations compared to using multiple discrete sampling points (McAlary et al. 2010). This method is described in the Advisory—Active Soil Gas Investigations (CalEPA 2015).

11H.4 Indicators, Tracers, and Surrogates

Indicators, tracers, and surrogates (ITS) refers to different tools that can help with VI pathway assessment and monitoring by helping to determine the best times and locations for future indoor air sampling and potentially characterize reasonable maximum exposure (RME) conditions (Schuver et al. 2018). Typically, use of these tools requires that measurements be made over time to determine trends rather than relying on single point-in-time measurements. Currently, regulatory guidance for using these methods to help with VI pathway assessment is limited.

- **Barometric Pressure Trends** – Measuring the pressure difference between the outdoor air and indoor air (indoor-outdoor pressure differential) can indicate whether atmospheric conditions are promoting VI into a building. During a 9-day study of a building in San Diego, California, Kram et al. (2020) observed that the controlling factor on TCE indoor air concentrations was the change in barometric pressure with higher concentrations detected as barometric pressure began to fall (increased VI) and, vice-versa, lower concentrations detected as barometric pressure began to rise (decreased VI).
- **Cross-Slab Pressure Differential** – Measuring the pressure difference between the subsurface and indoor air (cross-slab pressure differential) can indicate whether subsurface VFCs are potentially migrating into the building (i.e., depressurized building interior) or not (i.e., pressurized building interior) (USEPA 2015a). Pressure differentials typically are measured using micromanometers with pressure transducers and dataloggers installed at subslab probes. USEPA recommends that the pressure difference between the indoors and the subsurface be measured whenever indoor air samples are collected. Pressure differential data would be collected continuously starting several days before sampling and throughout the sample collection period. This involves measuring the differential at separate locations, away from probes used for subslab soil gas collection. Purging and sampling of such subslab probes could cause pressure disruptions.
- **Temperature and Differential** – Measuring the outdoor air temperature or the temperature difference between outdoor air and indoor air may indicate whether conditions favor VI and help determine when to sample indoor air. These measurements are most useful when daily outdoor temperatures are likely to be below 30 degrees Fahrenheit (Schuver et al. 2018).
- **Tracer Testing, Radon** – Naturally occurring radon may serve as a tracer to help identify those buildings that are more susceptible to soil gas entry than others because VI and radon entail similar mechanisms for soil gas migration and entry into structures (USEPA 2015a). However, radon concentrations in soil

gas are subject to spatial and temporal variability (Winkler et al. 2001). Radon may be used to confirm but not rule out whether the VI pathway is complete. Radon should not be used as the sole LOE to quantitatively estimate building-specific VFC AFs because changes in radon concentrations are not always proportional to changes in VFC concentrations (Schuver et al. 2018). Radon data can be used as an LOE to estimate a current, building-specific AF provided that the changes in VFC and radon concentrations are based on a robust dataset (i.e., sampling at multiple locations over multiple seasons) and demonstrated to be proportional. Continuous radon measurements have been used to determine when VI is occurring and to collect samples for VFC analysis during these periods. For instance, at newly constructed buildings, continuous radon measurements at subslab monitoring points can be used as a line of evidence to infer when near steady state vapor concentrations have been established.

11H.5 Mathematical Modeling

Mathematical models can be used to develop a conceptual understanding of the factors influencing VI at a particular site except for preferential pathways, which are not considered in currently available models. A commonly used mathematical model for VI is the USEPA implementation of the Johnson and Ettinger Vapor Intrusion Model (Johnson and Ettinger 1991; USEPA 2017b), which derives a vapor AF for predicting subsurface VI into indoor air and the resulting indoor air VFC concentrations. A similar VI mathematical model that additionally incorporates biodegradation and uncertainty analysis for the evaluation of petroleum VI is PVIScreen (USEPA 2016).

The use of models as an LOE to support risk management decisions requires more advanced characterization of subsurface conditions and contamination than is needed for screening. After preliminary VI screening and development of a complete CSM, site-specific modeling of VFC migration potentially can be used in developing site-specific AFs and media concentrations protective of human health to support risk management decisions. Models should be only used as an LOE in a multiple LOEs evaluation when the following conditions are met: (1) the nature and distribution of VFC contamination at a site has been adequately characterized, (2) the model is applicable to site subsurface conditions and to the contamination, and (3) the model is adequately constructed, documented, and verified (USEPA 2015a). The most important element to ensure confidence in a model as an LOE is verification of model predictions (i.e., indoor air sampling data confirms the predicted AF or that the AF is adequately protective). The following should be considered when developing site-specific risk assessments based on alternative soil gas-to-indoor air AFs:

- The CSM should be robust and based on sufficient LOEs to document that the assumptions of the model and inputs are consistent with site and building conditions (e.g., geology and distribution of subsurface concentrations are homogeneous).

- Vapor conduits should be investigated and ruled out as possible exposure pathways due to the inability of models to evaluate this vapor migration pathway (e.g., no current or potential future VI conduits intersect soil or groundwater contamination).
- Model inputs should account for potential future changes in building conditions that could reduce VI attenuation and increase VI risk as described in Section 1A. Potential future changes could be addressed by using conservative model inputs such that the apparent subslab to indoor air AF ($AF_{SS\text{-}IA}$) of the model is equal to the USEPA AF of 0.03 (or another justified VI database derived AF, as described in Section 11.I below). This allows for building specific modeling of the attenuation through the soil column from the subsurface source to the subslab ($AF_{SG\text{-}SS}$) while keeping fixed the attenuation across the foundation ($AF_{SS\text{-}IA}$). This approach will "lock in" the selected potential future $AF_{SS\text{-}IA}$ to account for future changes to that building while also allowing for the overall soil gas to indoor air AF ($AF_{SG\text{-}IA}$) to be reduced based on modeling of the attenuation through the soil column below the building. In the Johnson and Ettinger model, the $AF_{SS\text{-}IA}$ is represented by the ratio of the soil gas entry rate (Qsoil) and the building ventilation rate (Qbuilding). The following conservative model inputs are recommended to account for potential changes at buildings:
    - Qsoil – Calculate the Qsoil value by multiplying the Qbuilding value (discussed below) by 0.03 or another justified VI database derived AF (See Section 11.I).
    - Qbuilding – Recommended generic building parameters and the 10th percentile building air exchange rate of 0.18 hr^{-1} for residential or 0.6 hr^{-1} for commercial buildings (USEPA 2018) should be used to calculate a conservative Qbuilding value that is protective of current and potential future buildings as they change over time.
- Subsurface-based model inputs should use data based on adequately characterized geology/hydrogeology underlying the building (see DTSC 2011a, the current SF Bay Regional Water Board ESL User's Guide Section 5.4.4 and Appendix B Checklist for Vapor Intrusion Models).
- Models should use generic receptor-specific exposure factors (see Workbook Table IP-3 in the current ESLs) to account for the uncertainty in predicting values of site-specific exposure parameters for future building occupants.
- Modeled subsurface AFs should be applied to exterior near-source soil gas concentrations collected next to an existing building, similar to the sample location and depth recommendations described in Attachment 1, Section 10F.
- Subslab concentrations, if available, should be used to confirm modeled subsurface vapor attenuation between the subsurface vapor source and the building foundation.

11H.6 Passive Soil Gas Sampling

Passive soil gas samples should not be used in place of active soil gas samples collected for VI risk evaluations. The passive soil gas sampling method consists of burying an adsorbent material into subsurface soil and subsequently retrieving and measuring organic vapors passively amassed onto the absorbent material (CalEPA 2015). Traditionally, passive soil gas sampling has been used to: (1) evaluate whether a release has occurred; (2) characterize the overall near-surface soil gas contamination distribution at a site; (3) identify preferential pathways resulting from lithologic variability or sewer/utility corridors; and (4) qualitatively evaluate soil gas contamination in areas where active soil gas samples are difficult to obtain (e.g., near-surface groundwater conditions). This method is described in Appendix A of the Advisory—Active Soil Gas Investigations (CalEPA 2015). Recently, some interest has been expressed for using passive soil gas results quantitatively for risk assessment (ESTCP 2014; ASTM 2017; DoD 2019). Currently available passive soil gas sampling methods alone are not used to estimate human health risks and are generally not used to exclude or “screen out” buildings from further VI evaluation. If passive soil gas samples have been collected for another purpose and indicate potential health risks from VI, the results may be used to "screen in" or identify buildings where an indoor air investigation should be performed.

11H.7 Subslab Pneumatic Methods

This building-specific test method consists of monitoring ambient pressure gradients, performing vapor pumping tests to measure vacuum versus time and vacuum versus distance, subslab tracer testing to measure gas travel rates, flow rate and concentration measurements in vent pipes, and mathematical modeling using the Hantush-Jacob Leaky Aquifer Model (ESTCP 2018a; McAlary et al. 2018). The method is analogous to methods used for the design and performance monitoring of a groundwater extraction system. The data can be used to estimate the building-specific subslab AF via mass flux calculations, which provides insight into the protectiveness of the building structure and foundation under current conditions. Currently, regulatory guidance does not explain how to appropriately implement and interpret this method.

11I. Empirical Vapor Intrusion and Air Quality Databases

Empirical databases consist of data compiled from field investigations that are filtered and then statistically analyzed. The two more common types of VI-related databases include:

- Empirical VI Databases – These databases consist of indoor air and subsurface VFC or tracer data analyzed to evaluate AFs. These databases also include other types of information relevant for data interpretation (e.g., outdoor air data, geographic location, building type, building condition, sample date, distance from building, whether the HVAC system was on or off). The most widely known empirical VI database is the USEPA VI database (USEPA 2012c) but recently three other groups have published empirical VI databases using VFC data: (1) Derycke et al. 2018; (2) Ettinger et al. 2018 and Lahvis and Ettinger 2021; and (3) Hallberg et al. 2021. In addition, Nawikas (2020) compiled indoor and subslab tracer (radon) data to evaluate radon AFs for primarily commercial, slab-on-grade buildings in southern California.

- Empirical Air Quality Databases – These databases consist of outdoor air data or indoor air VFC data for buildings believed not to be undergoing VI. Outdoor air data are available via the California Air Resources Board i-ADAM database (https://www.arb.ca.gov/adam). Background indoor air databases by regulatory agencies include CalEPA (2009), USEPA (2011a), and Montana Department of Environmental Quality (2012). In addition, there are other useful studies, such as Rago et al. (2021) who collected indoor air samples for VFC analysis in office buildings and schools believed not to be undergoing VI. These databases and studies can be used as supporting LOEs to gain insight into the likelihood that VFCs detected in indoor air are due to indoor sources.

The following provides background on empirical VI database development, a description of the USEPA empirical VI database, and considerations for when to use results from other empirical VI databases.

- Background on Empirical VI Database Development – The typical VI database development process consists of the following:
    - The database is designed for content, quality assurance, and considering potential filtering and analysis options
    - The data are compiled
    - A quality control review is performed, and the data are filtered to remove problematic data (e.g., poor quality, incomplete information)
    - The data are screened to remove unwanted influences (e.g., VFCs from indoor sources) or otherwise segregate the dataset (e.g., petroleum VFCs separated from chlorinated VFCs due to the potential for biodegradation)
    - The data are statistically analyzed to evaluate AFs for categories of building types (e.g., all buildings, slab-on-grade foundation, crawl space foundation, residential, commercial, large industrial).
    - Lastly, a report is prepared discussing all of the above, presenting summary statistics, uncertainty analysis, and recommendations (if any).
- Regulatory Empirical VI Databases – Currently, the USEPA VI database (USEPA 2012c) currently is the only regulatory agency empirical VI database of indoor air and subsurface data available that evaluated AFs. The USEPA VI database has nationwide acceptance with 24 of 28 states with VI guidance using AFs equal to or more conservative than USEPA’s, as of March 2021. The USEPA VI database has strengths and limitations. Strengths include: (a) a robust dataset of

residential sites; (b) climatic conditions representative of some regions of California; (c) empirical subslab and indoor air paired data collected within 48-hours to address temporal and spatial variability concerns; (d) formal peer review of process and outcomes; and (e) an additional multi-year period of public availability prior to finalization of recommended AFs. Limitations of the USEPA dataset include: (a) very few California sites are in the database, (b) 75 percent of residential homes in the database have basements but only 5 percent of homes in California have basements, (c) USEPA did not evaluate commercial/industrial buildings due to insufficient data, and (d) groundwater and indoor air paired measurements had poor spatial correlation.

- Considerations for Using Results from Other Empirical VI Databases – In general, the primary concern when using the results of other VI databases as an LOE is how well the database development methodology matches with the USEPA VI database methodology. If the methodologies are significantly different, then the overseeing regulatory agency may need to evaluate a given database's methodology to determine whether the results are a suitable LOE. The following are some considerations when evaluating VI database methodologies:
    - Building-Specific AFs versus Data-Pair AFs – The USEPA VI database consists of AFs for individual buildings and statistical analysis was performed on the building-specific AFs. Other databases have employed a data-pair AF approach, which inherently treats each data pair as an independent measurement/result. This approach likely biases the resulting average AFs toward buildings with more sample locations and sampling events (e.g., larger commercial and industrial buildings).
    - Geographic Coverage – Given the expectation that different climatic conditions influence VI potential, databases that have limited geographic coverage may only be applicable to the area covered rather than all of California.
    - Data Pairing Criteria – Typically, indoor air and subsurface data are paired considering temporal concurrency and spatial proximity (e.g., USEPA only paired a subslab sample that was collected within 48 hours of the indoor air sample for a given building). While pairing data that are closely collected in time and space is generally agreed on as the best approach, it can significantly reduce the size of the dataset. Databases that include data that is not closely paired in space and time likely have greater uncertainty.
    - Number of Buildings – After filtering, the remaining data should come from a statistically sufficient number of buildings to be representative of the specific type(s) of buildings that the data will be used to evaluate. For instance, the USEPA recommended subslab AF of 0.03 is based on

431 paired subslab and indoor air measurements at residential buildings with basement or slab-on-grade foundations.

  - Other Factors – Other potential influences on database results can include conditions during testing (e.g., building ventilation, steady state conditions), and mixing data from samples with different characteristics (e.g., exterior soil gas and subslab soil gas).

11J. VIMS Construction

Inspections, construction testing, and documentation that a VIMS has been constructed in accordance with the design can be a qualitative LOE supporting interpretation of post-construction, pre-occupancy performance measurements (e.g., indoor air). To the extent the inspections, testing, and documentation are performed by an independent third party (preferably under direct agency oversight), greater weight could be assigned to this LOE. See also Section 4A.1.a (Indoor Air Data Objective 1).