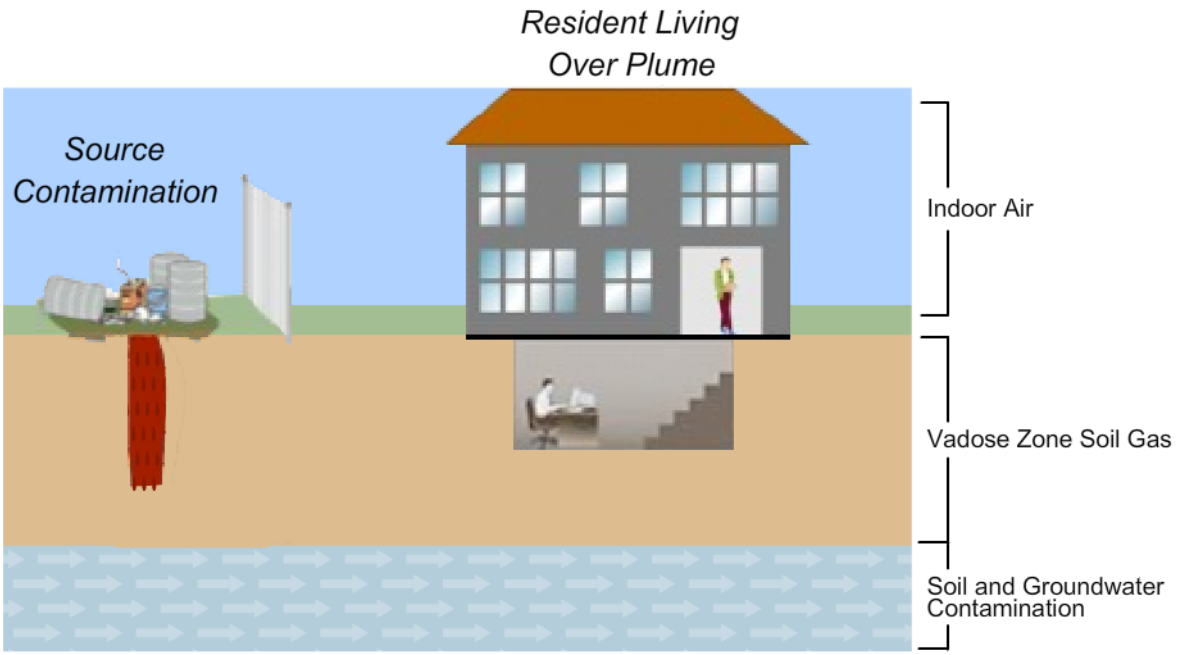
Vapor Intrusion

Title: Introduction
Text: Vapor intrusion (VI) refers to the migration of chemicals in gaseous (vapor) state from underground sources into the indoor air of an overlying building. Chemicals may be released underground into soil and groundwater in a variety of ways such as spills, past disposal practices, or leaking underground storage tanks. Chemicals that are sufficiently volatile may then evaporate into the soil gas and travel through the soil. If the soil is covered by a building, the vapor can enter the building through cracks, sumps, or other leaks in the foundation. The main chemicals of concern for VI are volatile organic compounds (VOCs) because they evaporate easily. If concentrations of the vapors in the indoor air become high enough, this can present a potential human health risk to residents within the building.

This Web tool will explore the basic concepts of VI, outline VI policy and guidance, provide an overview of the VI assessment process, and discuss sampling methods. A few case studies of investigations into VI are also included.

Basic Concepts



Courtesy of Battelle

Visual Description: Graphic showing contaminants leaking from drums into groundwater and migrating with the groundwater flow beneath a building. Contaminant vapors rise migrating to the building foundation.

Title: Basic Concepts of VI
Text: The basic concept of VI is that contaminant vapors move from the subsurface into the overlying building. For VI to pose a risk at a site, it must first be determined that a complete VI exposure pathway exists. A complete pathway must have the following:

- A source of contaminants (e.g., a spill or leak);
- A migration route to allow the contaminants to be transported to the point of exposure (e.g., through groundwater and soil gas); and
- A receptor or potential future receptor present at the point of exposure (e.g., humans living or working in a building at the site, currently or in the future).

The VI exposure pathway is a complex pathway that is influenced by many factors including characteristics of the contaminant (particularly volatility), the underground conditions that allow the contaminants to reach the building (geology, depth to groundwater, soil type, etc.), and characteristics of the overlying building (e.g., presence of a

basement or slab, cracks in basement floor or slab, vapor barriers, sumps, air flow within building, etc). In addition, other atmospheric factors can influence VI such as seasonal variations that affect air flow within a building and even daily variations in weather (wind, rain, barometric pressure). Finally, the presence of background sources of contaminants in outdoor air (e.g., local air pollutants) or indoor air (e.g., solvents from paints and hobbies, fumes from attached garages, dry cleaning, etc.) can make it difficult to determine whether VI is the source of the contaminants.

Click here to view a video with a brief introduction to VI issues.

Note: If you are having issues playing the video, view your browser settings and select a different media player as your default program.

Courtesy of Battelle

Visual Description: Video titled Understanding Vapor Intrusion: A Guide to Key Concepts and Principles

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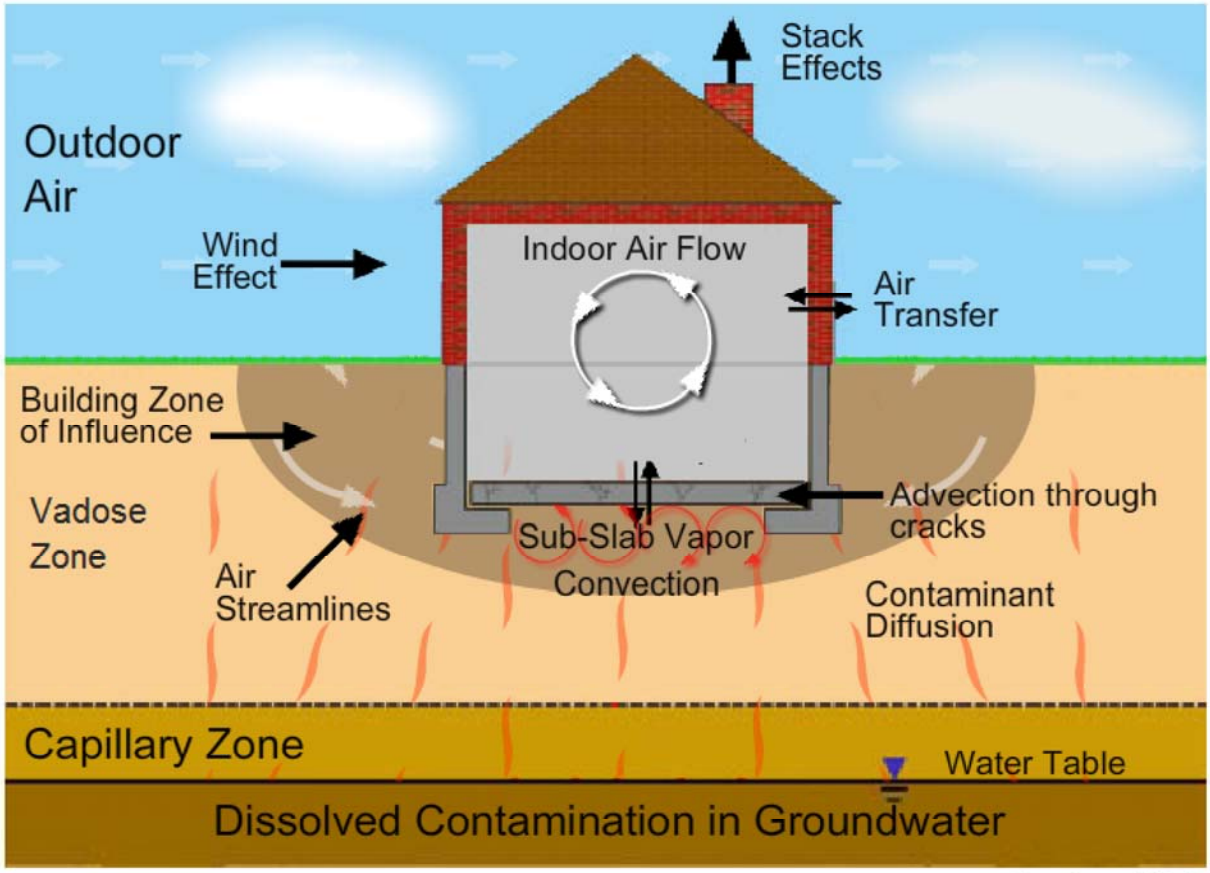
Title: Principles of Vapor Movement
Text: For VI to occur, volatile contaminants must partition from groundwater or soil to soil gas. Henry's Law constant (an air-to-water partition coefficient) and soil-to-water partition coefficients are critical parameters for determining the partitioning of a specific contaminant.

Once in the soil gas, other factors influence the movement of contaminants through the soil gas. Concentration gradients affect the vapor movement since vapors tend to move from areas of higher concentration to areas of lower concentration by molecular diffusion.

Pressure gradients also affect the movement of vapor into the building through advection and convection currents caused by factors such as weather, wind and building air flow. Pressure differences are generated due to the action of atmospheric air, ventilation systems, natural convection in soil and even temperature changes. When the internal air pressure within the building drops, external air or soil gas is forced into the building by advection. Advection occurs mainly in subsurface areas close to the building within the building zone of influence.

In addition, buildings may have preferential VI pathways such as sumps, unsealed utility connections, or cracks in the foundation or slab that allow vapors to move into the structure more quickly than through the slab or walls.

Advection and preferential pathways tend to be the dominant VI transport mechanisms in areas near the building whereas diffusion tends to play a more important role in subsurface areas farther away from the building.



Courtesy of Battelle

Visual Description: Graphic illustrating vapor movement in the soil below and around a building and inside the building.

Title: Contaminants of Concern for VI
Text: Contaminants of concern for VI are volatile compounds, i.e., those that evaporate easily and thus can potentially move through the soil into an overlying structure. The United States Environmental Protection Agency (US EPA) defines a chemical as volatile if its Henry's Law constant is 1 x 10^{-5} atm-m^3/mol or greater (2002). Due to their physical properties, volatile chemicals can migrate through unsaturated soil and into the indoor air of buildings located near zones of subsurface contamination.

VOCs - including such common chemicals as petroleum hydrocarbons (e.g., benzene) and chlorinated solvents (e.g., trichloroethylene [TCE] and tetrachloroethylene [PCE]) - are the class of chemicals of greatest interest for this pathway. Other chemicals of potential interest include mercury (the only volatile metal), various semi-volatile organic compounds (SVOCs) (e.g., polycyclic aromatic hydrocarbons [PAHs]), and certain pesticides. *Appendix A of the DoD Vapor Intrusion Handbook (2009)* identifies more than 100 chemicals that have sufficient volatility and toxicity to pose a theoretical VI hazard. Therefore, if it is known or reasonably anticipated that these chemicals may have been used or released at a site and if there is a potentially complete VI exposure pathway, they should be included in the VI investigation.

Title: Risk Communication
Text: Risk communication refers to informing building occupants and other stakeholders of the potential risks of VI. It is a very important factor to the success of VI investigations. The VI exposure pathway is often a more sensitive subject with building occupants than other pathways because it involves the air we breathe in our homes and workplaces. In addition, sampling to assess VI often occurs inside and beneath buildings, which can be disruptive to the occupants. Therefore, when VI is a potential concern, it is important to communicate with stakeholders early in the investigation in order to build credibility and trust. Also, the message needs to be presented in simple terms that people without a scientific background can understand.

The basic principles of risk communication are:
- Identify stakeholders that impact and are impacted by the investigation, so that all stakeholders can be included in risk communications

- Determine the underlying motivation of the stakeholders and/or perception of risk
- Utilize any third party supporters for suggestions or background information
- Become well informed quickly and pass on the information to the parties involved
- Ensure that all communicators are well trained
- Be aware of the process of working with the media. Include media relations specialists such as the Public Affairs Officer to interact with the media early in the VI investigation process.

Risk communication for VI often involves:
- Requesting permission from building occupants for access to conduct testing of soil/soil gas/indoor air/outdoor air
- Making available the results of the environmental tests
- Explaining the need for mitigation
- Obtaining permission to install mitigation systems
- Making arrangements to perform long-term operation and maintenance of VI mitigation systems (e.g., sub-slab depressurization (SSD) systems)
- Communicating with individuals in the neighborhood.

Effective risk communication can lead to improved relationships and cooperation from the building occupants, better legal standing, improved relationships with stakeholders and the public, and better management decisions with buy in from the stakeholders.

Courtesy of Clip Art

Visual Description: Drawing of people discussing documents and shaking hands

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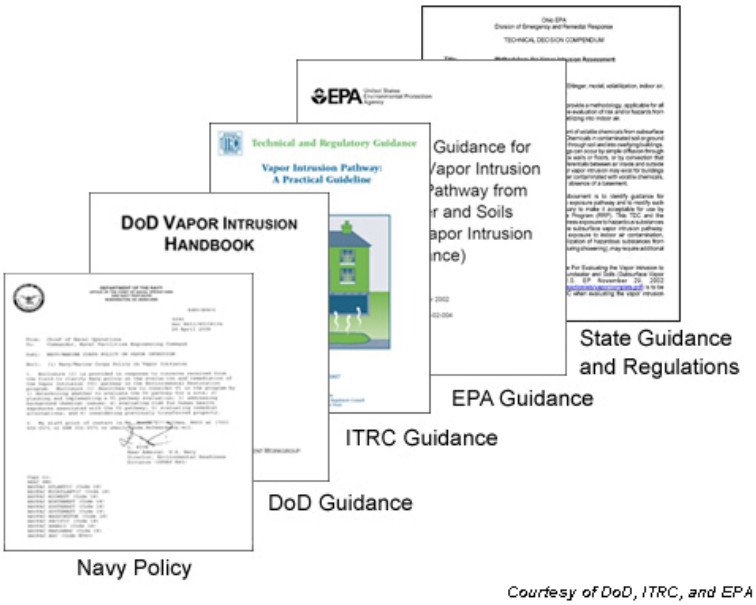
Title: Policy and Guidance
Text: Policy and guidance for assessing the VI pathway continue to evolve as more scientific knowledge becomes available and as more states adopt their own guidance and regulations. This has led to inconsistencies in the approaches taken to evaluate the VI pathway. Also, most available guidance focuses on residential scenarios while the Navy has many workplace and industrial settings that require evaluation. Therefore, the DON issued their own policy on VI in order to bring a consistent approach to VI assessment at Navy and Marine Corps sites and to ensure that occupational scenarios are considered where appropriate. The contents of the Navy's VI policy are described briefly in the next slide.



Courtesy of DoD, ITRC, and EPA

Visual Description: None.

Title: Navy/Marine Corps Policy
Text: The *Navy/Marine Corps Policy on Vapor Intrusion* was released in April 2008. This policy is applicable to site investigations and response actions funded under Environmental Restoration, Navy (ER,N) and Base Realignment and Closure (BRAC). The policy consists of six elements:

1. When to Evaluate the VI Pathway:
The VI pathway should be evaluated if volatile chemicals are present in groundwater, soil, or soil gas beneath existing structures or in areas where buildings may be constructed in the future and if there is potential for a complete exposure pathway to exist. Evaluation can occur anytime during the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process.

2. Planning and Implementing VI Assessments:
VI Assessments should be systematically planned. The Conceptual Site Model (CSM) should be defined including contamination location/type, exposure pathways, receptors, building structure and site geology. Also, Data Quality Objectives (DQOs) should be defined and appropriate sampling methodologies selected.

3. Background Chemical Issues:
ER,N or BRAC funds will not be used to address indoor air concentrations attributable to background sources, as is consistent with the *Navy Policy on Use of Background Chemical Levels (January 2004)*.

4. Potential Human Health Risk:
Evaluation of human health risk should be consistent with the receptors at the site (residential or industrial). Occupational Safety and Health Administration (OSHA) standards should be considered for evaluating risk for industrial settings. Only site-related volatiles should be addressed.

5. Evaluating Remediation Alternatives:
Remedial alternatives should be evaluated and must be protective of existing and future land uses.

6. Previously Transferred Property:
For previously transferred property, the current landowner must demonstrate that there are unacceptable VI risks attributable to a former Navy release, based on land use at the time of property transfer.

Title: VI Guidance Documents
Text: There are several general guidance documents available for VI:

- *DoD Vapor Intrusion Handbook (DoD, 2009)* discusses VI assessment in terms of screening level assessment, site-specific assessment and human health risk assessment. This document also discusses risk management and communication.

- *Vapor Intrusion Pathway: A Practical Guideline (Interstate Technology and Regulatory Council [ITRC], 2007)* provides an overview of VI, outlines preliminary screening of sites, site investigation and mitigation. This guidance provides a 13-step process for assessing VI.

- *Review of Best Practices, Knowledge and Data Gaps, and Research Opportunities of the U.S. Department of Navy Vapor Intrusion Focus Areas. (DON, 2009)* reviews best practices for various aspects of assessing VI and discusses areas where additional research is needed.

- *OSWER Draft Guidance For Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (US EPA, 2002)* provides guidance to the user when doing a screening assessment of VI and determining if the exposure pathway is complete and if there is any risk to human health. A draft *indoor air VI database was released by US EPA in March 2008 which supports the development of attenuation factors.*

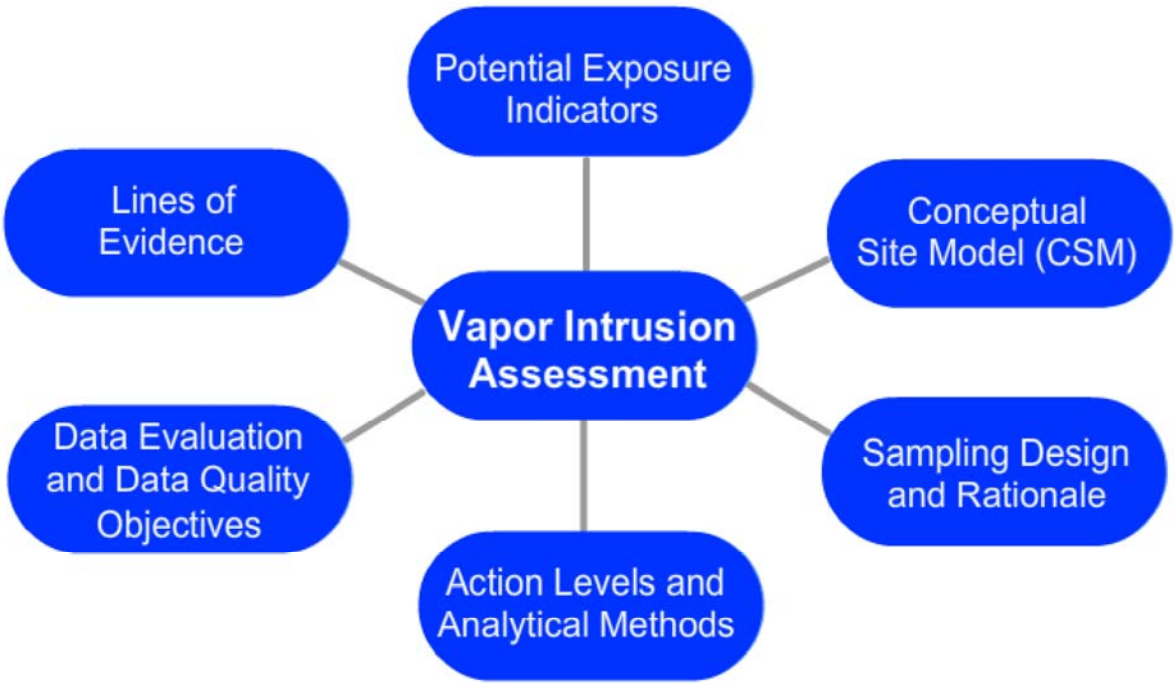
- *DON Guidance for Environmental Background Analysis, Volume IV: Vapor Intrusion Pathway includes information on methods for assessing background contaminants in indoor air. This document supports DON's Policy on Background Chemical Levels, which states that ER,N and BRAC funds will not be used to clean up contaminants that are attributable to background sources.*

Title: VI Assessment
Text: VI assessment is necessary when chemicals that are both volatile and toxic are present in the soil, soil gas, or groundwater below existing or future structures or when these chemicals have the potential to migrate below these structures. The goals of a VI assessment are to:

- Identify volatile sources
- Characterize VI potential
- When necessary, review options for control and mitigation of VI

The approach to assessing VI includes first evaluating whether VI poses an immediate threat to building occupants, and if not, then determining if the site can be eliminated from further evaluation based on conservative assumptions in a screening level assessment. If the site cannot be eliminated or if immediate action is not necessary, the site is further evaluated for VI using more site-specific information and a human health risk assessment may be performed. If the risk assessment determines that risks exceed acceptable levels, mitigation and remediation options are explored.

The figure illustrates the various components involved in VI assessment.



Courtesy of Battelle

Visual Description: Diagram of the six key components of VI Assessment.

Title: Potential Exposure Indicators
Text: Potential Exposure Indicators
At the outset of VI assessments, a complete exposure pathway needs to be established. Potential exposure indicators that help to determine if the exposure pathway is complete include:

- Noticeable odors in building basement
- Elevated concentrations in the sub-slab soil gas
- Elevated concentrations in soil, soil gas and groundwater
- Cracks with wet surfaces indicating seepage
- Elevated indoor air concentrations unaccounted for by background sources such as household materials.

Usually, more than one of these indicators must be positive for there to be potentially significant risk from VI.

Title: Conceptual Site Model (CSM)
Text: Conceptual Site Model (CSM)
A CSM aids in understanding the site including fate and transport of the contaminants and possible exposure pathways and receptors. In order to produce a comprehensive CSM, it is critical to understand the chemical and physical properties of the contaminant. If there are multiple exposure pathways, the CSM should explore all pathways and risks. The CSM also should be updated whenever new site information becomes available. The following information is recommended to be included when developing a CSM:

- Location and concentrations of contaminants
- Chemical properties of the contaminants (solubility, volatility, Henry's Law constant)
- Site geology and hydrogeology
- Depth to groundwater, hydraulic gradient and flow direction
- Background sources and concentration ranges of contaminants
- Receptors
- Building structure and air exchange characteristics

The Navy/Marine Corps Policy on VI requires that a CSM is developed and used to determine the proper sampling methodology for the site.

Title: Sampling Design and Rationale
Text: Sampling Design and Rationale
Sampling for VI can include collection of indoor air, outdoor air (for determining background contributions), near-slab soil gas, and/or sub-slab soil gas samples. Although not always required, indoor air sampling often is recommended when volatile contaminants are detected in soil gas or groundwater below buildings. It is often recommended that indoor air samples be collected at least during the heating season and often in multiple seasons to account for seasonal variation in building ventilation and to obtain representative samples. Sampling of outdoor air and sub-slab soil gas are often done simultaneously with indoor air sampling to provide multiple lines of evidence for the VI assessment.

A sampling and analysis plan (SAP) should be developed that clearly defines the sampling protocol that would produce the most useable information. The SAP should include DQOs to ensure that the data collected are of sufficient quality to support their intended use. Information on the extent of subsurface contamination, size and type of buildings on site, site geology and contaminant pathways should be used to determine the density, number and location of sampling points and should be included in the SAP. Contaminant fate and transport modeling can also be conducted to predict indoor air contaminant concentrations. The model used most often is the *Johnson and Ettinger (J&E) model* developed by the US EPA.

Title: Analytical Methods and Action Levels
Text: Action Levels and Analytical Methods
The US EPA has prepared standardized protocols for measuring the concentration of specific contaminants in soil, soil gas, and groundwater. The methods used should have low enough detection limits to allow comparison to risk-based action levels for the site. Action levels vary from state to state and should be included in all planning documents and approved by stakeholders involved. Later in this tool, a list of methods used for analyzing specific volatile contaminants is provided.

Title: Data Evaluation and Data Quality Objectives
Text: Data Evaluation and DQOs
The quality of data available should be evaluated. The following questions should be considered:

- How old are the data and do the data reflect current conditions?
- Were sample collection methods reliable?
- Were all suspected chemicals tested for?
- Are reporting limits at or below VI screening criteria?
- Has the contaminant migrated further since data were collected?
- Are there additional buildings on site that may be affected?

If additional data are needed, site-specific DQOs should be developed prior to collecting this data. Guidance on how to apply the DQO process to generate performance and acceptance criteria for environmental data can be found in US EPA's Guidance on Systematic Planning using the Data Quality Objectives Process (US EPA, 2006). DQOs should include a statement of the problem and should identify the decisions to be made including the inputs to the decisions, the study boundaries, decision rules, limits and sample design.

Title: Multiple Lines of Evidence
Text: Multiple Lines of Evidence
Once the assessment is complete, it is recommended that multiple lines of evidence be used to determine whether or not the VI pathway is complete rather than relying on a single line of evidence. Lines of evidence may include:

- Soil gas, near-slab soil gas, sub-slab soil gas, indoor air, outdoor air and groundwater data
- Background indoor air data
- Building survey results
- Ratio of contaminants in soil gas to indoor air
- Impact of site geology
- Results of fate and transport modeling
- Results of risk assessment
- Site or building ownership and control

Title: VI Assessment Process
Text: The VI assessment process consists of two phases:

Screening Level Assessment
The Screening Level Assessment is used to obtain a general understanding of the possible risks posed by VI. It first evaluates whether exposure to the vapors poses an immediate risk to building occupants. Next, the screening level assessment compares existing site data (typically soil gas or groundwater data) with conservative generic risk-based screening values. In some cases, the data may demonstrate the site does not pose a VI risk and requires no further action. In other cases, it may be determined that more definitive information is required to determine the level of risk and the process proceeds to a site-specific assessment.

Site-Specific Assessment
The Site-Specific Assessment is the phase where additional site-specific data such as near-slab and sub-slab soil gas data and indoor and outdoor air samples are collected. These data may be used in a human health risk assessment to determine if a contaminated site poses a potential health risk to people who may be exposed to the contaminants and to determine if remediation is required. The risk assessment procedure should include data evaluation, exposure assessment, toxicity assessment and risk characterization. Multiple lines of evidence may be used to evaluate the magnitude and extent of VI. Depending on the results of the investigation and risk assessment, it may be determined that either no further action is necessary, that monitoring is required to make sure that VI does not pose a hazard in the future, or that remediation and/or mitigation are warranted.

More information on both screening level assessments and site-specific assessments is provided on the next two slides.

Title: Screening Level Assessment
Text: The exact steps required for a screening level assessment may vary depending on site conditions and applicable state regulatory requirements; however, the process generally consists of first developing a conceptual site model, determining if the site presents an acute hazard that requires immediate attention, and then determining whether the site clearly poses no significant risk from the VI pathway or whether more site-specific information needs to be collected. It is important early on to confirm that chemicals of sufficient volatility and toxicity are present in the subsurface and that a potentially complete human exposure pathway exists. It is also important at the outset to identify the regulatory program governing the site to ensure that all decisions are in accordance with the regulatory requirements.

The ITRC guidance (2007) describes seven steps that are often included in the screening level assessment process:

Step 1: Does the site represent an acute exposure concern? (e.g., immediate health hazard or an explosive hazard). This would require an immediate action such as evacuation of the building.

Step 2: Are there sufficient characterization data to evaluate this pathway?

Step 3: Are any of the site contaminants of concern both volatile and toxic?

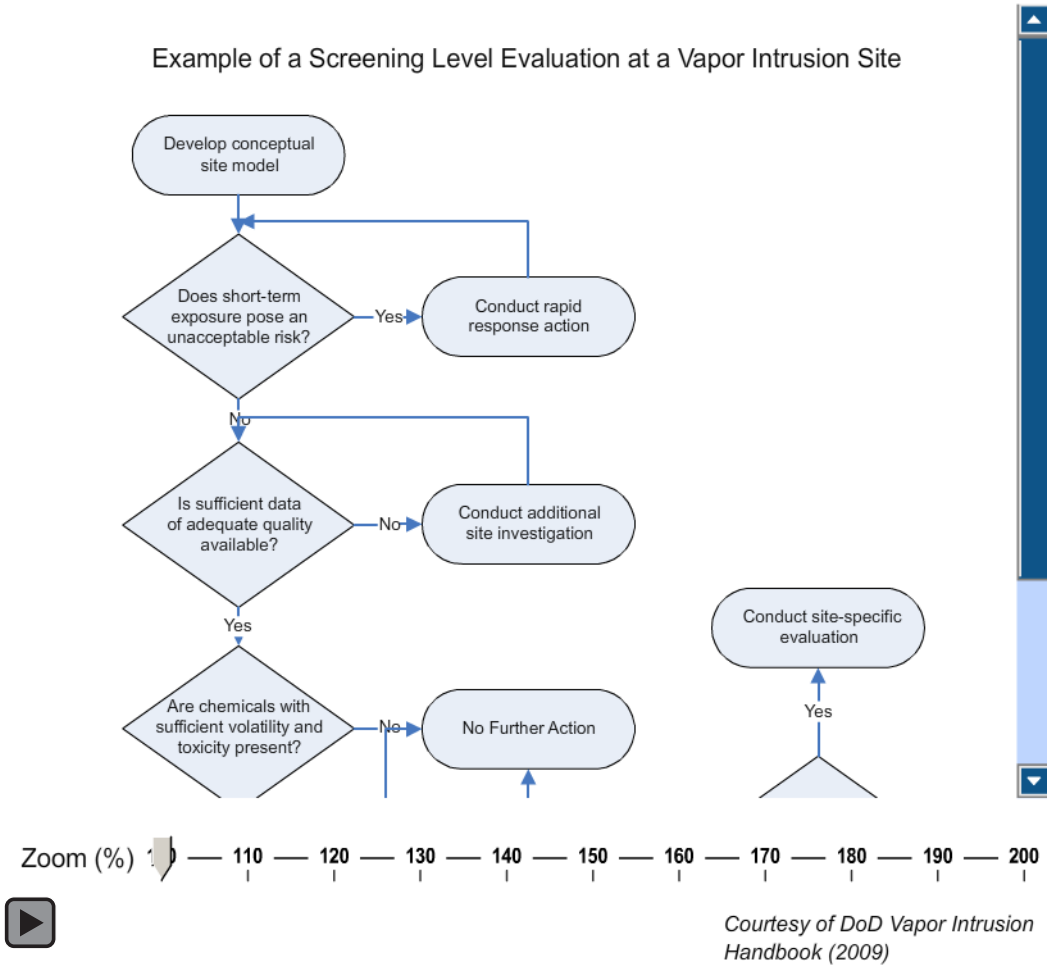
Step 4: Are buildings located in close proximity to volatile chemicals in soil, soil vapor, or groundwater? (i.e., less than 100 ft from impacted soil, soil gas, or groundwater)?

Step 5: Identify the appropriate occupant exposure scenarios and screening levels for the site.

Step 6: Do the data exceed the appropriate generic screening levels?

Step 7: Does an exceedance of the generic screening level warrant further investigation?

An example of the decision process for a VI screening level assessment is shown below.



Visual Description: VI Assessment Flow Chart Illustrating Steps 1-7 for the Screening Level Assessment.

Title: Site-Specific Assessment
Text: Site-Specific Assessment phase involves collecting additional information about the site-specific conditions to determine whether the site presents a risk to the receptors and whether it requires mitigation. Typically, the site-specific assessment involves collecting samples to better define the indoor air concentrations resulting from VI. Sampling may include groundwater, soil gas, indoor air, outdoor air (to determine background) and sub-slab soil gas. These data may be used to calculate site-specific health risks or they may be compared to more site-specific screening concentrations. Site-specific assessment also includes evaluation of background sources that may be contributing to the concentrations.

The ITRC Guidance (2007) describes six steps for site-specific assessment:

Step 8: Choose an investigative strategy

Step 9: Design a VI work plan

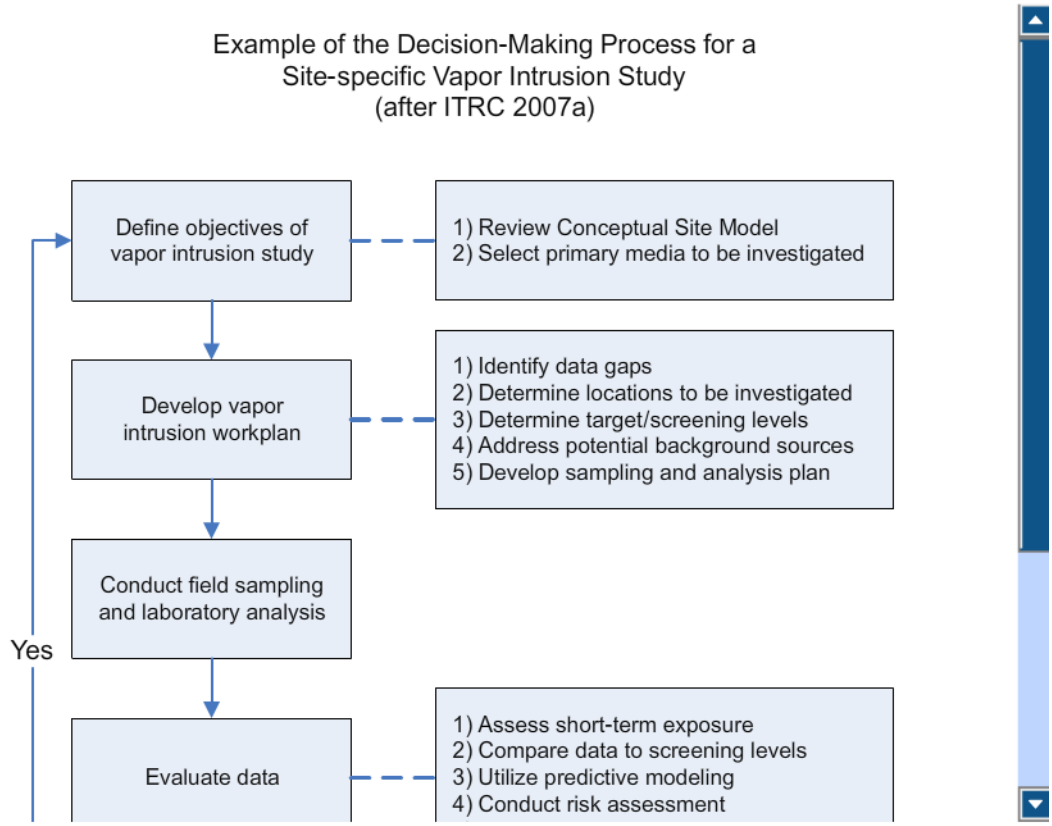
Step 10: Implement the VI work plan

Step 11: Evaluate the data

Step 12: Is additional investigation warranted?

Step 13: Is mitigation warranted?

A flow chart illustrating the decision process for the site-specific assessment is shown below.



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Enlarge Graphic

Courtesy of DoD Vapor Intrusion Handbook (2009)

Visual Description: VI Assessment Flow Chart Illustrating Steps 8 through 13 for the Site-Specific Assessment

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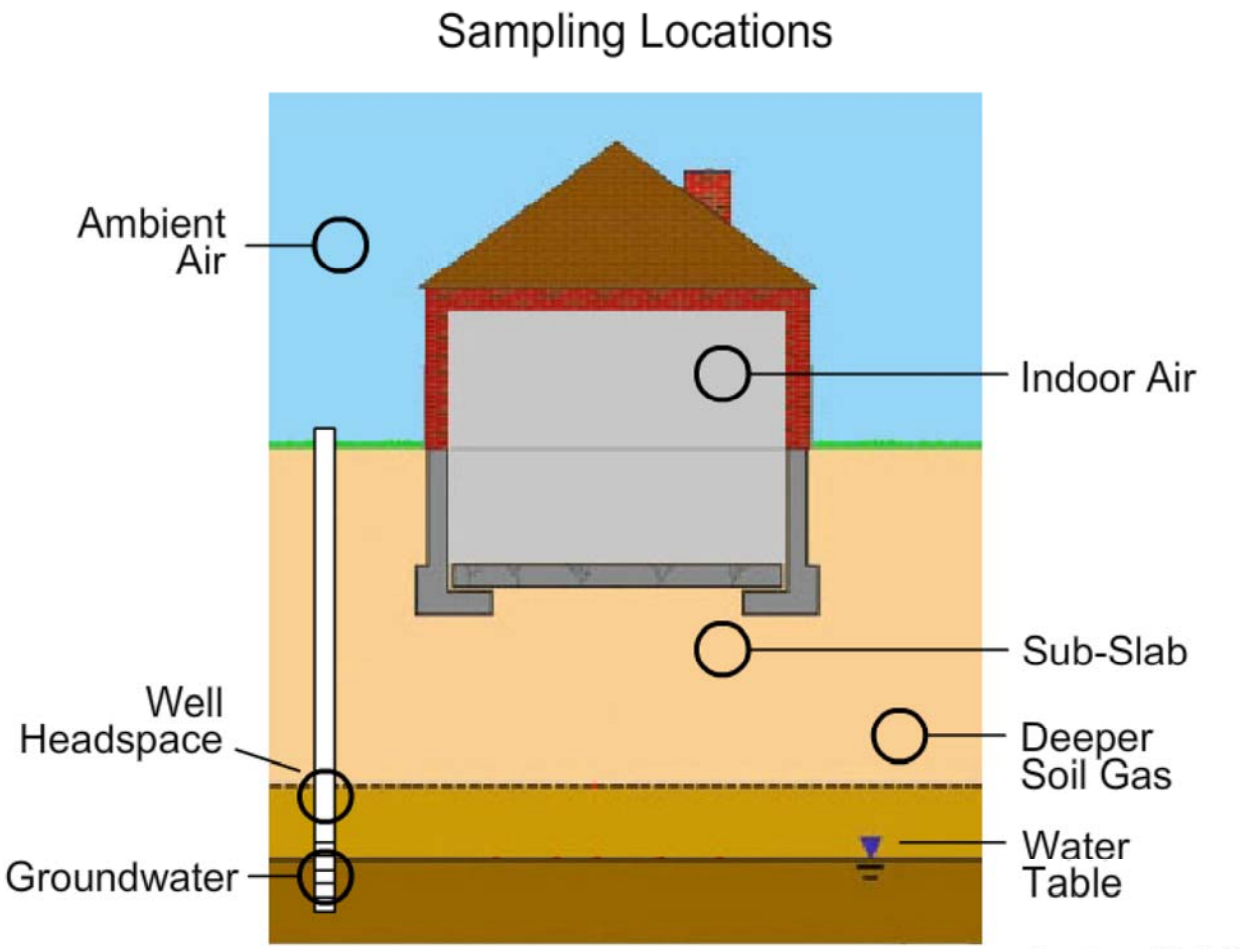
Title: Sampling
Text: In order to assess the VI pathway at a site, it may be necessary to obtain and analyze samples from multiple media. The density, number, and location of the samples taken depends on the nature and extent of the subsurface contamination, the building being investigated, site geology, and location of pathways for contaminant transport. For buildings currently in use, samples generally should be taken if the building is within approximately 100 ft vertically or horizontally of the contaminated media (although some state regulators may require sampling if contaminants are present at distances greater than 100 ft). At times, additional samples are taken from soil, near-slab, and sub-slab samples.



Visual Description: Drawing illustrating locations where samples may be collected for assessing the VI pathway.

Title: Soil Gas Sampling
Text: Soil Gas Sampling - Soil gas is often the preferred subsurface media sampled for screening assessments of the VI pathway and may also be important for more site-specific assessments. Soil gas samples must be taken from the appropriate depth, as determined by the site-specific geology and type. Generally, soil gas samples collected outside the building footprint should be at least five feet below ground surface (bgs) to avoid atmospheric influence. Soil gas samples can be collected by active sampling (most common), passive sampling, and surface-flux chambers.

- Active sampling - Soil gas probes allow direct collection of a sample by inserting the probe into the ground and drawing on a vacuum (pump, syringe, evacuated canister) to obtain a sample. Soil gas probes give concentration-based data, which can be input directly into contaminant transport models or a risk assessment.

- Passive sampling - Passive sampling involves the burial and subsequent retrieval of an absorbent material designed to collect volatile chemicals present in the soil vapor over time. Passive samplers measure chemical mass rather than concentration and quantitation generally is not possible because accurate uptake rates of different chemicals onto passive samplers are unknown. Currently, passive soil-gas data are not considered suitable for quantitative risk assessment; however, research is ongoing to improve methods for quantitative passive sampling.

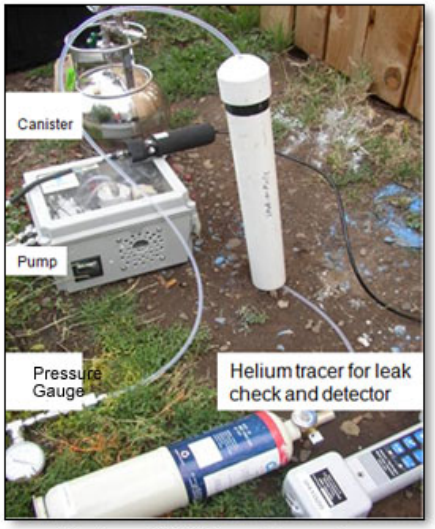
- Flux chambers – A box is placed directly on the ground or building floor and captures the chemicals in soil gas that are leaking through the area covered by the flux chamber. The box can be left on the same spot for relatively long periods of time (hours or days). Flux chambers can provide useful information regarding the migration of chemicals from the subsurface. Not all agencies will approve their use. California Department of Toxic Substances Control (DTSC) will accept them as a qualitative screening tool only and will not allow their results to be used in a quantitative risk assessment.

Sub-slab and near-slab soil gas sampling is performed to determine if volatile vapors are present directly below or near a building.

- Sub-slab sampling - This requires drilling through the basement or slab of the building to directly measure soil gas contaminant concentrations that may have accumulated right below the building. An electric hand drill or concrete corer is recommended to drill through the slab with minimum disruption to occupants. California DTSC recommends that, for a building larger than 5,000 sq ft, one sample is taken every 1,000 sq ft. In general, the size of the hole

should be 1 to 1.25 inches and should be advanced through the slab and three to four inches into the sub-slab material.

- Near-slab sampling - These samples are taken within the zone of influence of the building, i.e., within 100 ft of the building. This method does not require indoor drilling so the building foundation does not have to be disturbed; however, recent studies indicate that near-slab samples may not correlate well with sub-slab concentrations and suggest that if near-slab sampling is required, samples should be taken as close as possible to the building (Swanson et al, 2009). Samples should be taken deeper than five feet bgs to prevent interference from precipitation and advective flow caused by the building.



Active Soil Gas Sampling

Courtesy of CH2MHill (2008)

Courtesy of CH2MHill (2008)

Soil Gas Sampling

Courtesy of U.S. Navy (2008)

Courtesy of U.S. Navy (2008)

Electric Hand Drill for Subslab Sampling

Subslab Sampling

Courtesy of U.S. Navy (2009)

Visual Description: Four photos of soil gas sampling equipment.

Title: Air Sampling
Text: Air Sampling - To determine if contaminated soil gas has migrated to the indoor air of buildings, indoor air sampling is conducted. The sampling duration, number of samples, and sampling location are key parameters for air sampling. Sample canisters and flow regulators are used and can be set to collect samples over a specific time period. Air samples should also be collected during different seasons of the year (generally at least once in summer and once in winter). Also, air samples should be collected from breathing zone height (approximately two to five feet above the floor). There are several methods available for collecting air samples:

- Grab samples - Air grab samples refer to collecting an air sample at one point in time. The length of time could be a second or a few minutes. This is done to get a general idea of the contaminants present in the air.

- Time-integrated monitoring - This is the most common method of obtaining air samples because the sample is collected over a sufficiently long period of time to get a representation of the exposure. The sampling procedure generally is designed to capture the daily exposure duration, typically 24 hours for residential settings and 8 hours for occupational settings.

- Real-time monitoring - Samples are collected rapidly over a few minutes and transported via heat trace lines to a point of analysis. US EPA's trace atmospheric gas analyzer (TAGA) is one example of a real time monitoring device.

- Passive sampling - An absorbent material that absorbs VOCs is used. The material is left in place over a long period of time and then analyzed to determine the presence of VOCs over an extended period of time. Similar to the challenges with passive soil gas sampling, passive indoor air samplers measure chemical mass rather than

concentration and quantitation generally is not possible because accurate uptake rates of different chemicals onto the passive samplers are unknown. Currently, passive soil-gas data are not acceptable to most regulators for use in quantitative risk assessment; however, research is ongoing to improve methods for quantitative passive sampling.

- Portable direct measurement sampling - This involves the use of handheld devices to analyze air samples on-site. Their results are generally used only as a screening tool to determine which chemicals are present and at what approximate levels, because the instruments lack analytical sensitivity (i.e., they can only read single digit parts per million levels or possibly triple digit parts per billion levels), and they also lack specificity (e.g., they cannot distinguish between halogenated compounds such as TCE and PCE). They are usually held in close proximity to sump pumps, cracks and other openings in the foundation to determine if volatile chemicals are migrating through these spaces. The most commonly used detectors in handheld devices are flame ionization detectors (FID) and photoionization detector (PID).

Indoor Air Sampling

Courtesy of U.S. Navy (2009)

Outdoor Air Sampling

Courtesy of U.S. Navy (2008)

Visual Description: Two photos of summa canisters used for collecting air samples.

Title: Groundwater and Soil Sampling
Text: Groundwater Sampling – Contaminated groundwater is the primary source of contaminants that contribute to VI. The contaminant plume migrates with the groundwater bringing the contaminant in close proximity to buildings. Collection of groundwater samples for evaluating VI involves taking samples from wells screened at the top of the aquifer where volatile chemicals are partitioning to the vapor phase. Previous studies have indicated that volatile contaminants within one meter below the surface of the water table can contribute to VI. If the contaminant is deeper in the aquifer, it is less likely to migrate to the soil gas. Direct push wells or permanent monitoring wells can be installed to collect groundwater samples depending on the location of the site.

Soil Sampling – Soil sampling is not the most appropriate method for collecting data for VI assessments. It is difficult to minimize loss of volatiles from soil samples during collection and analysis. Soil samples, therefore, do not give an accurate representation of the concentration of the VOCs present.

Title: Special Considerations for VI Assessment
Text: The science surrounding VI continues to evolve and it is important that RPMs seek out the best information currently available as methods for assessing VI are refined to provide more accurate results. There are several additional factors that should be considered during the VI assessment process. These include:

- Variability in Attenuation Factors
- Spatial and Temporal Data Variability
- Conceptual Site Model Development
- Background Issues
- Multiple Lines of Evidence
- Current vs. Future Land Uses
- Johnson and Ettinger (J&E) Model Assumptions
- Accounting for Biodegradation

Title: Variability in Attenuation Factors
Text: The attenuation factor (AF) refers to the ratio of indoor air concentration divided by sub-slab vapor concentration and it reflects the proportion of contaminant passing from the sub-slab into the indoor air. The AF can vary by orders of magnitude and this variability can contribute to uncertainty, which may lead to conservative decisions for protection of health. It may be appropriate to sample indoor air and employ tools that distinguish background sources before making overly conservative decisions.

Title: Spatial and Temporal Data Variability
Text: Subsurface Soil Gas Spatial Variability - Soil gas and sub-slab vapor can vary spatially by orders of magnitude. It is possible to have buildings right next to each other with vastly different concentrations. Therefore, it may require that more samples be collected to adequately characterize the uncertainty. Also, this information should be presented to the stakeholders so they understand the complexity and they should be involved in making decisions about the site.

Subsurface vs. Indoor/Outdoor Air Spatial Variability - Spatial variability in the subsurface is much higher than in indoor or outdoor air. Thus, fewer indoor and outdoor air samples are generally needed compared to subsurface samples. Again, stakeholders should be involved in making decisions.

Temporal Variability - Temporal variability is site- and media-specific. Temporal variability typically is similar to spatial variability in the subsurface. Two or more rounds of sampling are generally required to adequately characterize uncertainty.

Title: Conceptual Site Model Development
Text: It is important to have a good understanding of the CSM. Factors in the CSM that can affect VI include whether the building envelope is under positive or negative pressure (negative is generally assumed), preferential pathways by which contaminants can enter the building, whether the source beneath the building is the same as a source distant to the building, and the adequacy of analytical and hydrogeologic data. An RPM should update the CSM as new data becomes available.

Title: Background Issues
Text: Background Indoor Air Sources - A building survey should be conducted to identify background sources of contaminants. Background sources can include industrial, commercial or household products (e.g., solvents, cleaners, scented candles, paint strippers), building materials (carpets, insulation, paint, wood finishes), combustion processes (engines, home heating, smoking, cooking), and other occupant activities (welding, metal cutting, hobbies). These surveys should be as thorough as possible.

Background Indoor Air VI Screening Levels - Background concentrations may exceed screening levels. Thus, it is important to distinguish background sources of contaminants when assessing VI.

Background Outdoor Air - Background outdoor air sources can include permitted point sources, auto emissions, and natural sources (e.g., fires). These concentrations can vary considerably and site-specific assessment is critical. Background outdoor air can contribute significantly to indoor air contaminant concentrations and it is important to distinguish these sources.

Title: Multiple Lines of Evidence
Text: With multiple lines of evidence, it is important to prioritize the significance of the data types. Generally, indoor air data are more significant than soil gas data, which are more significant than groundwater data. It is important to understand and agree with stakeholders on how data and multiple lines of evidence will be used by implementing the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) and developing DQOs. It should not be assumed that VI is occurring just because indoor air is greater than outdoor air. Stakeholder agreement is critical when defining levels of significance.

Title: Current vs. Future Land Uses
Text: It is important to track land use of the site because unexpected re-zoning can occur. The Navy's VI policy requires that current land use should be evaluated unless it is a BRAC site or unless residential use is part of the Base plan. Long-term life cycle costs and mission needs (e.g., land use controls vs. costs for cleanup to residential levels) should be considered.

Title: Johnson and Ettinger (J&E) Model
Text: Use of the J&E model for screening or validated applications is appropriate; however, model results can vary by orders of magnitude. Users should consider incorporating a validation step to calibrate the model. Empirical data may be needed to validate site-specific modeling. Also, site-specific factors that should be considered include the presence of non-aqueous phase liquid (NAPL) beneath the building, shallow groundwater in contact with the foundation, extreme heterogeneity (e.g., fractured bedrock), significant lateral flow or preferential pathways, and buildings with crawlspaces, since these may have significant effects on model results. The model is not appropriate under all conditions and it is important to understand the CSM before attempting to apply the model.

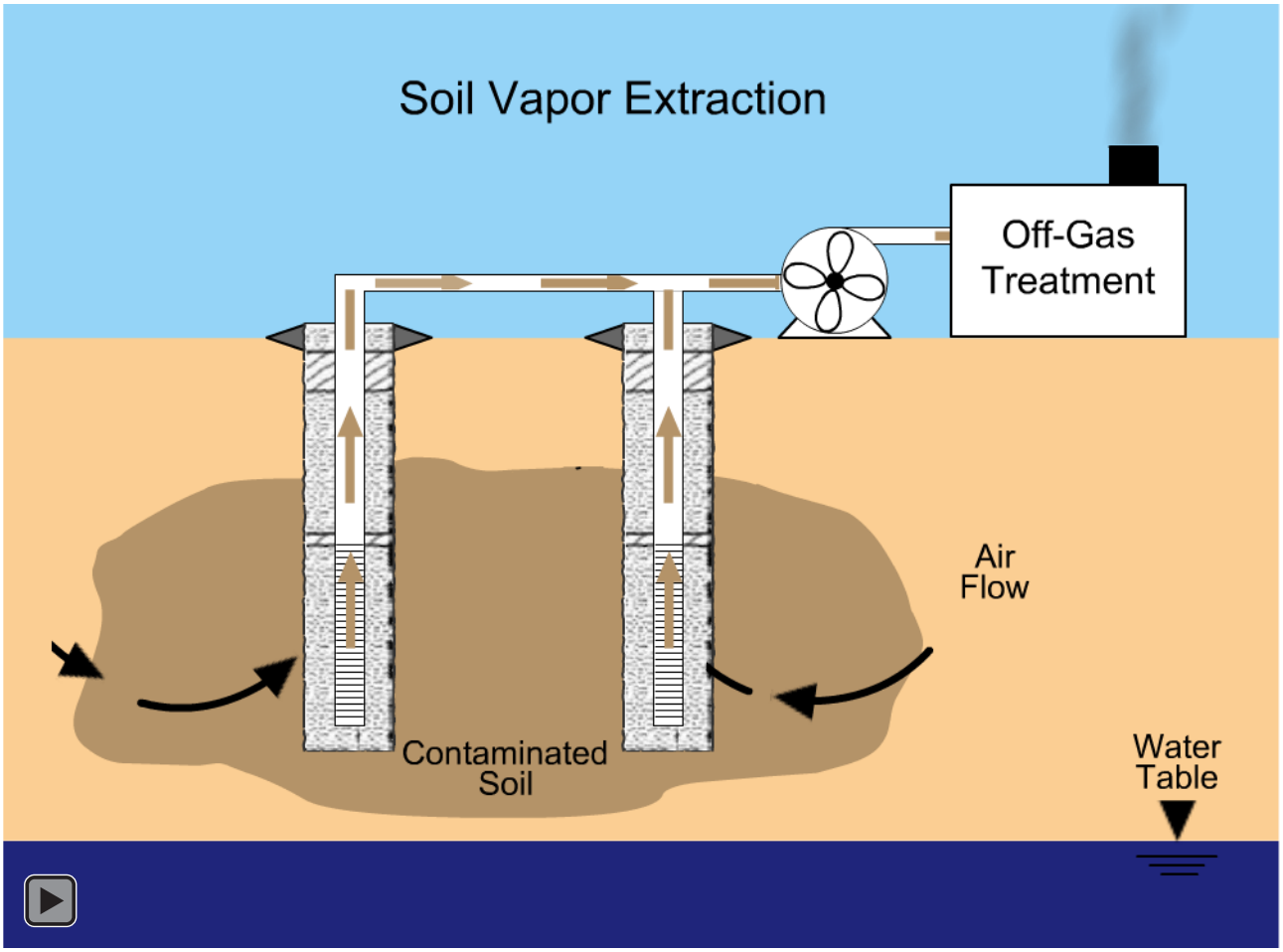
Title: Biodegradation
Text: Petroleum hydrocarbon AFs are consistently lower than the default values due to the effects of bioattenuation; however, few agencies allow for bioattenuation. There are methodologies available to incorporate bioattenuation and calibrated models can result in 10- to 100-fold differences in AFs for hydrocarbons.

Title: Remediation
Text: Remediation techniques aim to treat, remove, or reduce the source of volatile contaminants present in the soil, soil gas, and groundwater. Techniques for remediation include soil vapor extraction, excavation, bioremediation, and groundwater treatment systems.

- Soil vapor extraction involves installing a series of pipes underground close to the contamination. Suction is applied to the pipes causing air currents to flow through the soil channeling the contaminated soil gas in the direction of the suction. Typically, the contaminated air then undergoes some type of off-gas treatment such as passing the extracted vapor over a series of filters to remove the contaminant.

- Soil is sometimes excavated to remove the bulk of the contaminant mass especially when the contaminant release is shallow.

- Bioremediation - both natural and enhanced bioremediation can reduce contaminant concentrations. Natural attenuation allows contaminants to degrade naturally either by bioremediation due to microbes present in the subsurface or by abiotic methods. For enhanced bioremediation, microorganisms and substrate can be injected into the aquifer to promote biological degradation of the contaminant.
- Groundwater can be treated by several techniques including pump and treat where the groundwater is pumped out, treated above ground by carbon or ozone, then reinjected into the aquifer. Other treatment techniques include installing a barrier to prevent the contaminant plume from migrating or an active wall to destroy the contaminants as the groundwater passes through it.



Visual Description: Animated graphic of a soil vapor extraction system.

Title: Mitigation
Text: Mitigation techniques refer to measures taken to reduce contaminant levels in indoor air, thus reducing exposure. These measures are often implemented simultaneously with remediation activities until the VI source can be removed/treated sufficiently to reduce the risk to building occupants below levels of concern. Mitigation steps may be different for acute and chronic risks.

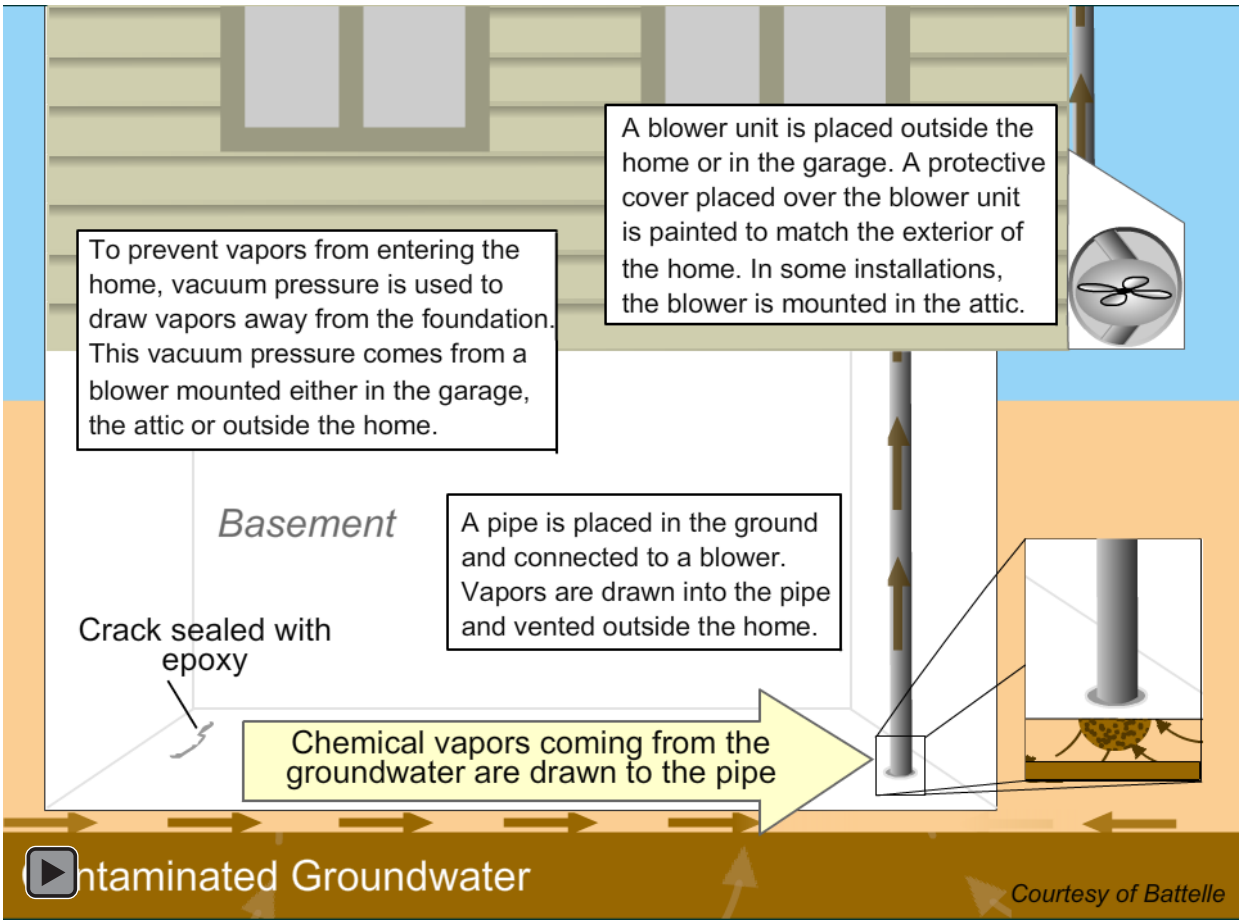
Mitigation for acute risks requires a quick response in order to minimize exposure to the contaminant or to minimize other risks such as explosion. Local health services, fire department and other authorities should be informed. The building should also be evacuated until mitigation measures can be implemented. Indoor air treatment systems using air pollution control equipment (e.g., carbon adsorption systems) are sometimes used for mitigation of acute risks. (These systems can also be used for mitigation of chronic risk; however, they are generally not the preferred long-term solution.)

Mitigation for chronic risks is required to prevent long-term exposure. The following scenarios provide some suggestions for mitigation of chronic risks.

- Sub-slab depressurization systems create a pressure differential across the slab that favors movement of indoor air down into the subsurface. Active systems utilize a powered fan to pull soil gases from beneath the slab. Vapors are collected in pipes that are routed up the side of the building or through the roof to be released to the atmosphere. Passive systems rely on natural thermal and wind currents to move the sub-slab vapors to external vents.
- The heating, ventilation, and air conditioning (HVAC) system in a building can be manipulated to create a positive pressure that will prevent contaminated soil vapors from moving into the building. This type of mitigation can only be applied to relatively tight buildings where there are few doors or other openings.
- Vapor barriers can be installed to reduce the transfer of contaminated vapors into the building. Vapor barriers are typically thermoplastic or elastomeric flexible membranes or spray-on rubberized asphalt emulsions that form a seal to prevent entry of vapors. In new construction, they are generally placed beneath the slab; however, they can be used in existing buildings particularly in crawlspaces with dirt floors.
- Sealing cracks, sump pumps and other spaces in the basement floor and wall can help prevent vapors from migrating to the indoor air. Epoxy sealants are often used. This technique alone may not be adequate for large basements. Also, sealing cracks and other openings is an important step when other mitigations systems such as sub-slab depressurization systems are being installed, to ensure that those systems operate effectively.

Installing a Vapor Barrier

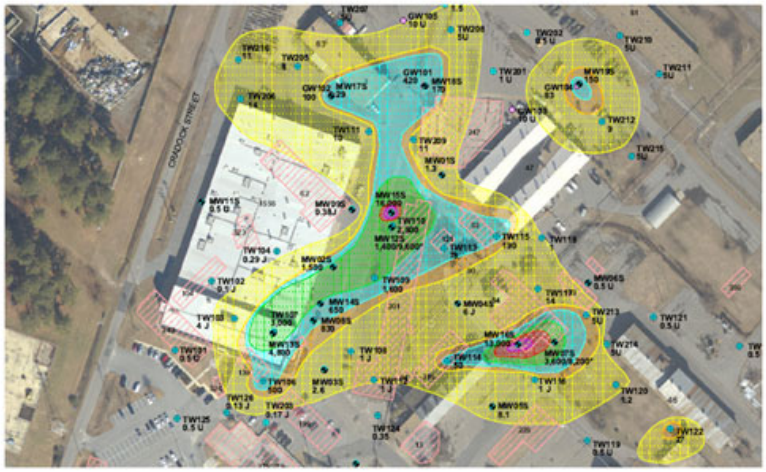
Courtesy of CH2MHill (2008)



Visual Description: Photo of a vapor barrier being installed and an animated graphic of a sub-slab depressurization system.

Title: Case Studies
Text: Three case studies of sites that were assessed for the potential completeness of the VI pathway are described here. The case studies outline how the VI assessment was done, the final study conclusions, and the lessons learned about each site.

Title: St Juliens Creek Annex Case Study
Text: St. Juliens Creek Annex (SJCA) is located in Chesapeake, VA. An 8-acre plume of TCE is present at SJCA Site 21 and is currently beneath several buildings on the site. The concentration of TCE in the shallow groundwater was as high as 16,000 ug/L. The depth to groundwater at this site is approximately 5 ft bgs and a confining unit is present at about 21 ft bgs. The VI pathway is being evaluated using the ITRC guidance seven-step screening level assessment process.



Courtesy of U. S. Navy (2008)

Visual Description: Map of groundwater plume at St. Juliens Creek Annex Site 21.

Title: St Juliens Creek Annex Case Study
Text: The following observations were made during the screening level assessment of Site 21.

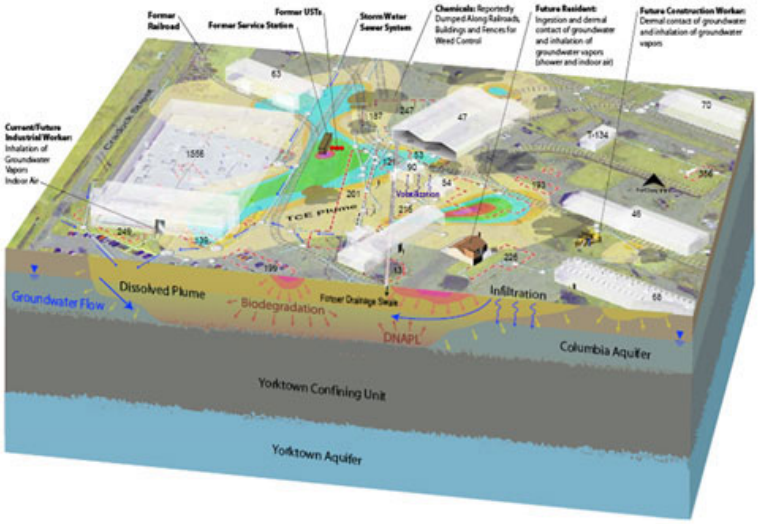
Step 1) No acute hazards were identified.

Steps 2 & 3) Historical data were reviewed for chlorinated VOCs in groundwater and soil, and TCE was identified as a contaminant of concern.

Step 4) At Site 21, seven buildings were within 100 ft of impacted subsurface. Three buildings were occupied; four buildings were unoccupied and used for storage or abandoned.

Steps 5 & 6) In the screening level assessment, maximum groundwater concentrations exceeded US EPA (2002) generic screening levels. Therefore, Johnson & Ettinger (J&E) modeling of a future resident receptor was performed. Residential risk was $>10^{-4}$ for all seven buildings. Then the J&E model was refined using site-specific inputs. Industrial risks for two of seven buildings was $>10^{-4}$. A detailed survey was performed at the three occupied buildings. One building is open to outdoor air and the groundwater beneath it was not impacted; therefore, the Navy proposed a No Further Action (NFA) determination for that building. However, the regulators expressed concern with the validity of the J&E model for Site 21 due to shallow groundwater (~5 ft bgs), preferential pathways (e.g., sumps), and possible presence of non-aqueous phase liquid (NAPL).

Step 7) It was determined that further investigation is warranted or required at all three occupied buildings at Site 21.



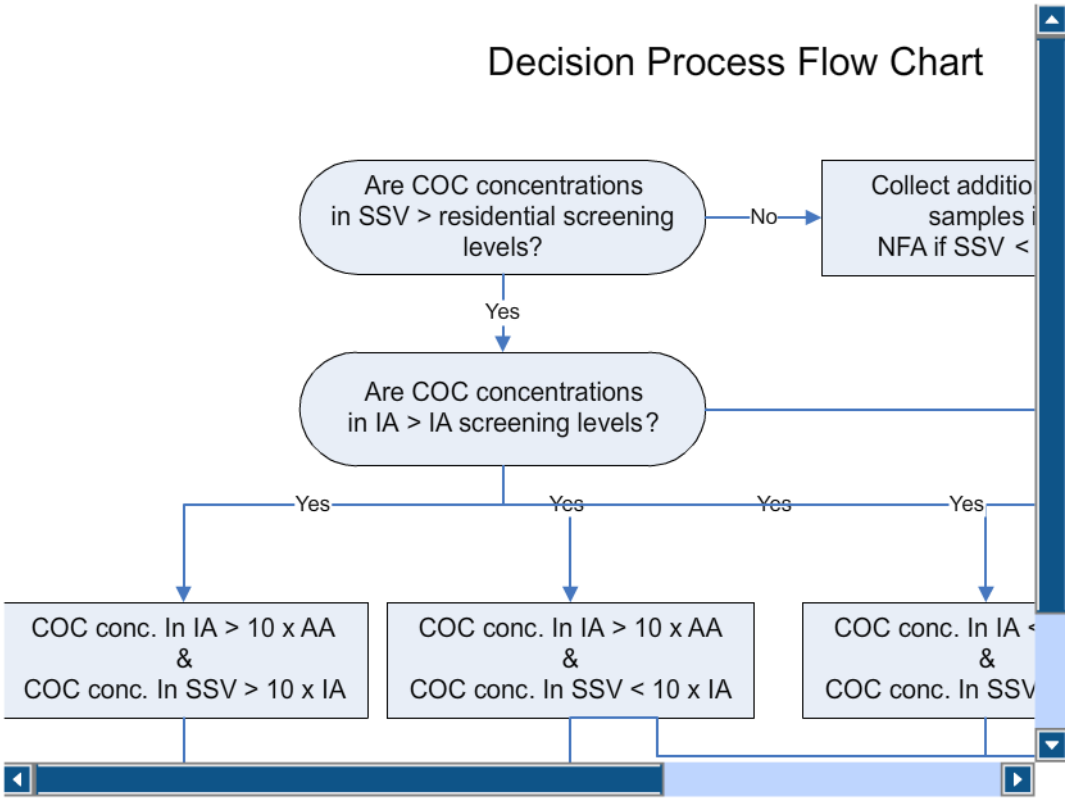
Courtesy of U. S. Navy (2008)

Visual Description: Cross-section illustrating the Conceptual Site Model for St Juliens Creek Annex Site 21.

Title: SJCA Site 21 Site-Specific Assessment
Text: Since further investigation was warranted, plans for site-specific assessment were developed. The next steps will be:

- Collect groundwater samples at top of aquifer adjacent to buildings
- Collect sub-slab and/or indoor/outdoor air data and perform a multiple lines of evidence (MLE) evaluation.

The flow chart shown at the left illustrates the decision process used for this site comparing indoor air (IA) with ambient air (AA) and sub-slab vapor (SSV) concentrations to determine if VI is significant.



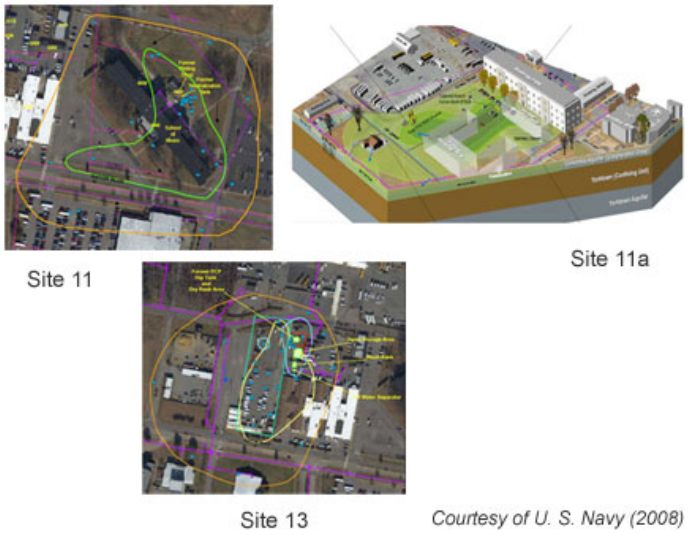
Visual Description: Flow diagram of the decision process for site-specific assessment at St Juliens Creek Annex Site 21

Title: SJCA Site 21 Lessons Learned
Text: The lessons learned from SJCA Site 21 were as follows:

- Screening level assessment identified buildings for site-specific assessment.
- Lines-of-evidence may be subjective. The J&E modeling, building survey, and distribution of groundwater VOCs indicated no further action (NFA) was required; however, building sub-slab and/or indoor/outdoor air data have been requested to "prove the negative."
- Early partnering with stakeholders is critical. Discussions on what is significant should be initiated early and one should expect extended discussions and multiple reviews.

Visual Description: Photos of buildings at St Juliens Creek Annex Site 21

Title: NAB Little Creek Case Study
Text: Three sites (Sites 11, 11a, and 13) at Naval Amphibious Base Little Creek in Virginia Beach, VA were evaluated for VI. At the Base a chlorinated VOC plume was present at the bottom of the aquifer. A clay confining layer was present at approximately 25 ft bgs and the water table was about 5-7 ft bgs. The VI pathway is being evaluated using the ITRC guidance seven-step screening level assessment process.



Visual Description: Maps of groundwater plumes at NAB Little Creek Sites 11 and 13 and a cross-sectional diagram of the groundwater plume and CSM for Sit 11a.

Title: Sites 11 and 13 Screening Level Assessments
Text: Screening level assessments were conducted for Sites 11 and 13, and the following was determined:

Step 1) No acute hazards were identified.

Step 2) Groundwater data were available.

Step 3) Chlorinated VOCs were present in groundwater.

Step 4) Buildings included a School of Music and various industrial buildings located over the plume.

Steps 5 & 6) In the screening level assessment, groundwater data collected from the top of the aquifer showed non-

detect or low-level detections. Detections were below site-specific J&E-based industrial screening levels. Building surveys indicated significant VI was not likely.

Step 7) Further investigations were not warranted and the conclusions from screening were incorporated into approved Records of Decision (RODs).

Site 11: Former Planting Shop and Current School of Music

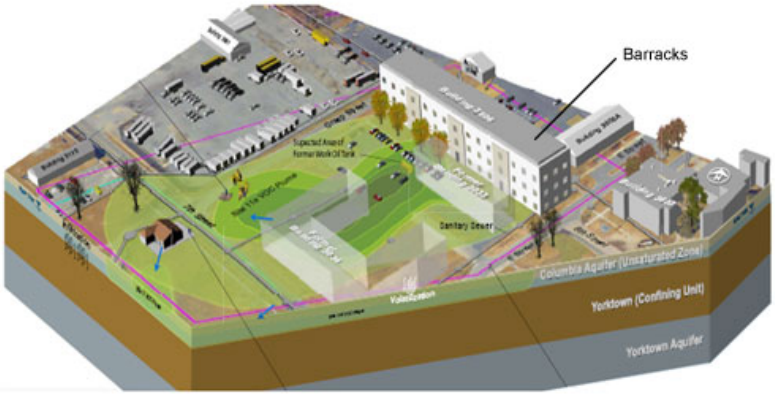
Site 13: Historical Dip Tank, Racks, and Storage Area

Courtesy of U. S. Navy (2008)

Visual Description: Maps of groundwater plumes at Sites 11 and 13 showing sources and buildings.

Title: Little Creek Site 11a VI Assessment
Text: A screening level assessment at Site 11a produced similar results to Sites 11 and 13. However, to address regulators concerns, a proposed site-specific assessment is being developed. This assessment includes:

- Sampling groundwater at top of aquifer adjacent to the building
- Collecting sub-slab and/or indoor/outdoor air data and performing a multiple lines of evidence evaluation



Site 11a: Former Waste Storage Tank and Current Barracks Building

Courtesy of U. S. Navy (2008)

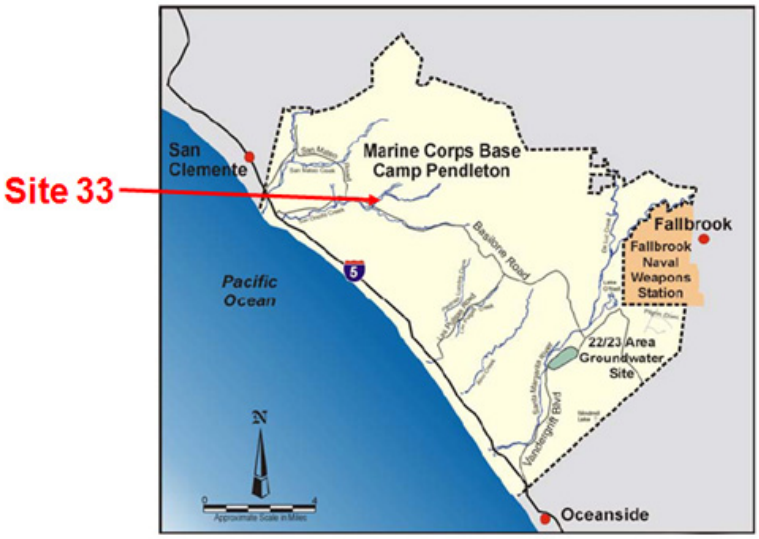
Visual Description: Cut away cross-sectional diagram of the CSM for Site 11a showing location of the plume and barracks.

Title: NAB Little Creek Lessons Learned
Text: From the VI assessment at NAB Little Creek, the following conclusions were drawn:

- Screening level assessment was sufficient at Sites 11 and 13 and NFA conclusions were incorporated into approved RODs.

- Screening level conclusions for Site 11a were similar to Sites 11 and 13 (groundwater concentrations were non-detect at the top of aquifer from all sides of the building and no further investigation was recommended); however, the regulators requested sub-slab and/or indoor/outdoor air data to "prove the negative".
- Data from site-specific assessment at Site 11a will be useful for future screening level assessments. Regulators have requested confirmation of the ROD conclusions for Sites 11 and 13 at the 5-Year Review.

Title: MCB Camp Pendleton Case Study
Text: Marine Corps Base (MCB) Camp Pendleton, Site 33 in North San Diego County, CA was used as a gun cleaning and former solvent storage/usage area. PCE is present in the shallow groundwater between 7-25 ft bgs. The maximum PCE concentration was 13,000 ug/L. The 150 – 200 ft plume lies below a portion of the buildings on site. The VI pathway is being evaluated using the ITRC guidance seven-step screening level assessment process and the additional six-step site-specific assessment.



Courtesy of U. S. Navy (2008)

Visual Description: Site map showing the location of Site 33 on MCB Camp Pendleton.

Title: MCB Camp Pendleton Site 33 - VI Assessment
Text: A VI assessment of Site 33 was performed with the following results:

Step 1) No acute hazards were identified.

Step 2) Groundwater, soil and soil gas data were available.

Step 3) Chlorinated VOCs were present in soil, groundwater, and soil gas.

Step 4) Three buildings are present on the site: a hobby/maintenance shop, a supply warehouse, and a combat training building. These are older, Quonset-like structures with slabs greater than one foot in thickness. The buildings have passive open-end ventilation and are not used regularly.

Step 5 & 6) A screening level assessment was not performed since no state and US EPA regional screening levels for VI (pre-2002) were available.

Step 7) It was determined that further investigation was warranted.

Step 8) Strategy - Samples collected included groundwater using direct push technologies and well samples, exterior soil gas, and one sub-slab sample in the corner of the building overlying plume.

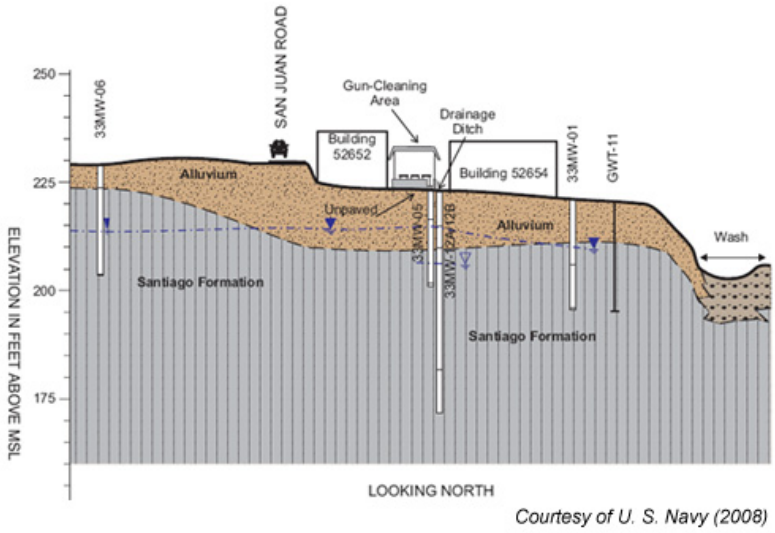
Steps 9 & 10) A VI work plan was designed and implemented.

Step 11) Evaluation of the data included:
- Site-specific J&E modeling of current workers in building over plume (Risk was approximately 3×10^{-7} based on sub-slab soil gas)
- Default J&E modeling of future indoor workers and residents (Risk was $>10^{-4}$ based on maximum exterior soil gas)

Remedial Investigation (RI) conclusions were that:
- No significant VI risks to current receptors were identified.

- Risks were greater than target levels for future indoor workers and residents.

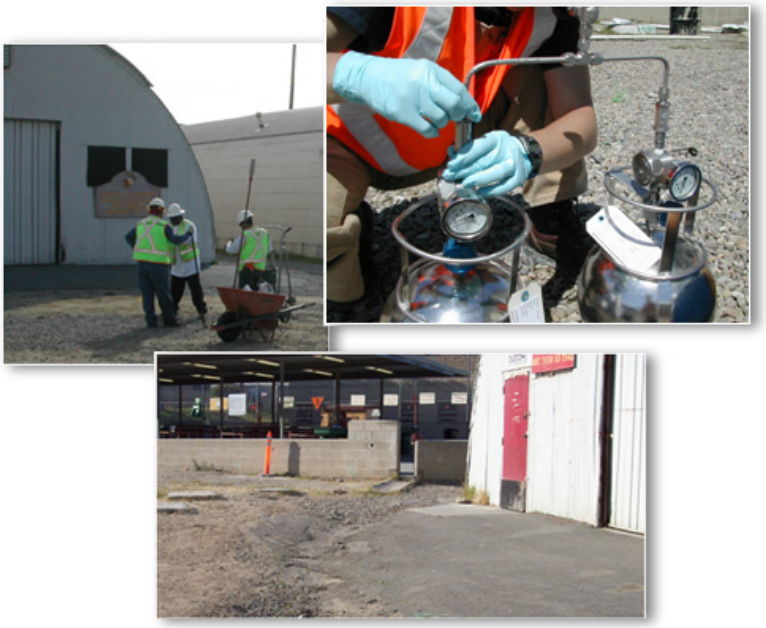
Step 12) No additional investigation was recommended. Groundwater and soil gas cleanup goals for VI were established in the Feasibility Study (FS). The maximum contaminant level (MCL) was the lowest level for groundwater and was selected as the cleanup goal. Soil gas cleanup goals for future workers/residents were based on the J&E model. The remedial investigation/feasibility study (RI/FS) was finalized in September 2008. The Proposed Plan and ROD are in progress.



Visual Description: Cross-section showing the geologic formations, groundwater monitoring wells and locations of buildings above.

Title: Site 33 Lessons Learned
Text: The lessons learned from the VI assessment of MCB Camp Pendleton Site 33 include:

- One option during a VI assessment is to bypass the screening level assessment.
- Indoor air sampling may not be necessary.
- Site-specific modeling using soil gas, sub-slab, and/or groundwater data was accepted.
- No unacceptable VI risk was present under current land use.
- It is important to present VI-based cleanup goals in the FS because it creates flexibility for decision makers and future indoor workers and residents.
- Success to date is due in part to early and continuous partnering with stakeholders.



Courtesy of U. S. Navy (2008)

Visual Description: Photos of the site and soil gas monitoring equipment.

Title: Summary
Text: In summary, VI is an increasingly important exposure pathway for environmental remediation. Several important things to consider when assessing the VI pathway are as follows:

The Navy policy (2008) requires that VI be addressed at all ER,N and BRAC sites impacted by volatile chemicals.
- Assessment of VI must be consistent with current and reasonably anticipated land use.
- VI is not the only pathway to consider in risk assessment.

Follow guidance in the DoD Vapor Intrusion Handbook (2009).
- This guidance is consistent with ITRC (2007) VI guidance.
- US EPA currently endorses ITRC (2007) and is in the process of developing documents to supplement guidance on assessing VI. Watch for new developments and updates in their guidance materials as the science behind VI evolves.

Stakeholder involvement is critical during planning, implementation, and assessment …. not all stakeholders think alike.

Conservative/variable regulatory numerical screening levels and guidance often result in site-specific investigations.
- Maintain awareness of regulatory requirements.
- Navy uses California DTSC toxicity value for TCE, rather than US EPA provisional value.

"Variability is the Norm"
- Acknowledge confounding factors and uncertainties.
- Plan accordingly and involve risk managers/stakeholders.

Do not hesitate to consult technical experts.
- VI experts, mechanical engineers, industrial hygienists, building superintendents, risk assessor/communicator, etc.
- The science continues to evolve.

Share lessons learned!
- This supports the Navy's initiative to develop best practices.
- VI assessment results will be more likely to be defensible and successful.

Title: References
Text:

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