PUBLIC HEALTH RESPONSE WORK PLAN

Evaluation of Potential Exposures from Vapor Intrusion

U.S. MARINE CORPS BASE CAMP LEJEUNE
CAMP LEJEUNE, NORTH CAROLINA

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

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Prepared By:

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Abbreviations

AF	attenuation factor
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
CAP	Community Assistance Panel
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	constituents of potential concern
CV	comparison value
ft	feet
GA Tech	Georgia Institute of Technology
GIS	geographic information system
GRASP	Geospatial Research, Analysis, and Services Program
HPFF	Hadnot Point Fuel Farm
HPIA	Hadnot Point Industrial Area
IRP	Installation Restoration Program
J&E	Johnson and Ettinger
L/m^3	liters per cubic meter
LNAPL	light non-aqueous phase liquid
LOAEL	lowest-observed-adverse-effect-level
MCB	U.S. Marine Corps Base
NAPL	non-aqueous phase liquid
NESDI	Navy's Environmental Sustainability Development to Integration
NOAEL	no-observed-adverse-effect-level
OSHA	Occupational Safety and Health Administration
PCE	tetrachloroethylene
PHA	public health assessment
RCRA	Resource Conservation and Recovery Act
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TCE	trichloroethylene
1,2-tDCE	trans-1,2-dichloroethylene
UCL	upper confidence level of the mean
$\mu g/m^3$	micrograms per cubic meter
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride

VI	vapor intrusion
VICV	vapor intrusion comparison value
VOC	volatile organic compound

1. Scope of the Public Health Assessment

In August 1997, the Agency for Toxic Substances and Disease Registry (ATSDR) released a public health assessment (PHA) of U.S. Marine Corps Base (MCB) Camp Lejeune in North Carolina [ATSDR 1997]. The 1997 PHA identified a public health hazard from past exposures to volatile organic compounds (VOCs) in the three drinking water systems on the base. Since the 1997 PHA, additional scientific information has expanded the knowledge base related to exposures to the contaminants of concern in drinking water at MCB Camp Lejeune. In January 2017, ATSDR released findings from the revised PHA of the health effects of exposure to VOCs found in the drinking water at MCB Camp Lejeune [ATSDR 2017]. ATSDR continues to conduct additional activities, including studying the association of health outcomes to drinking water exposures on the base. ATSDR reports on MCB Camp Lejeune and reference materials are available at http://www.atsdr.cdc.gov/sites/lejeune/index.html.

Volatile chemicals in contaminated shallow groundwater can seep upward through the ground surface into indoor air of overlying or nearby buildings—a process termed vapor intrusion (VI)[1]. Breathing indoor air contaminants in MCB Camp Lejeune's buildings due to vapor intrusion is a potential pathway of exposure to shallow groundwater contaminants. The same contaminants that were present in drinking water at MCB Camp Lejeune may also be of concern for vapor intrusion. These include chlorinated solvents, such as trichloroethylene (TCE), tetrachloroethylene (PCE), vinyl chloride (VC), and related compounds and hydrocarbon compounds, such as benzene, toluene, ethylbenzene, xylenes, and others. It should be noted that vapor intrusion is only one source of these contaminants in indoor air. These contaminants are present in many industrial and household products and are consequently also released directly into indoor or outdoor air from those sources.

At the time of the 1997 PHA, neither ATSDR nor the U.S. Environmental Protection Agency (USEPA) had developed guidance for evaluating indoor inhalation exposures from vapor intrusion, and neither agency regularly conducted such evaluations. The planned Vapor Intrusion Public Health Assessment (VI PHA) has two objectives:

1. In the VI PHA, ATSDR will evaluate the public health implications of potential current and historical exposures to indoor air contamination that may have resulted from vapor intrusion into buildings on the base.
    a. However, given the magnitude of the site (i.e., thousands of buildings), ATSDR's focus will be on those buildings where the agency's public health recommendations will have the greatest impact; essentially, ATSDR will place a higher importance on identifying current exposures. Although the agency will focus on identifying current VI exposures, ATSDR will evaluate past VI exposures when there are sufficient data to do so.
2. In the VI PHA, ATSDR will also evaluate the effectiveness of vapor intrusion mitigation systems installed in 21 buildings on base in reducing indoor air contaminant concentrations to protect health.

[1] Vapors are also released to outdoor air. However, vapors disperse more quickly in outdoor air. Therefore, high concentrations are uncommon outdoors.

a. The agency will conclude that a building's mitigation system is effective at reducing indoor air contaminant concentrations if indoor air contaminants in that building are below levels expected to harm human health.

Overall, ATSDR's evaluation will concentrate on contamination that may have resulted from vapor intrusion into buildings, as opposed to other sources of volatile chemicals in indoor air that relate to industrial and household products. Note that if ATSDR finds an indoor air concern not associated with vapor intrusion, the agency will inform MCB Camp Lejeune of the concern.

ATSDR's planned approach to develop the VI PHA is documented in this work plan, which was released for external peer review in late January 2018. Peer reviewer comments and ATSDR's responses are contained in Appendix D. Appendix E provides the curriculum vitae of each external peer reviewer of the work plan. Note that the order of the curriculum vitae does not align with the external peer reviewer numbers provided in Appendix D.

2. Background

2.1 *Site Description*

MCB Camp Lejeune is located in the coastal plain of North Carolina, in Onslow County. The base is southeast of Jacksonville, NC and about 50 miles northeast of Wilmington, NC. The base covers a large area, approximately 151,000 acres (about 233 square miles), with 14 miles of beach on the Atlantic Ocean. Operations began at Camp Lejeune during late 1941 [Watson 1995]. The base is densely populated. At any one time, it has housed as many as 43,000 active duty military personnel and 50,000 dependents.

2.2 *History of Groundwater Contamination*

Over the years, unlined landfills, leaking storage tanks, and other activities related to the use and disposal of hazardous materials have contaminated soil and groundwater at several areas on the base. Discovery of contaminated water supplies at MCB Camp Lejeune initiated a series of assessments of groundwater contamination:

- In 1983, MCB Camp Lejeune conducted an initial assessment of potentially contaminated areas. Seventy-six potentially contaminated waste disposal sites were identified through records reviews and personnel interviews. MCB Camp Lejeune listed 22 of those sites for further investigation.
- MCB Camp Lejeune was listed on USEPA's National Priorities List on October 4, 1989. As a result, the Installation Restoration Program (IRP) conducted a series of assessments of groundwater contamination under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority.
- Additional assessments of groundwater contamination by refined petroleum products from leaking above-ground and underground storage tanks were conducted under Resource Conservation and Recovery Act (RCRA) authority.

- In 1997, ATSDR released a PHA evaluating health risks from exposures to harmful substances in the environment at MCB Camp Lejeune, including exposures from consuming groundwater. An updated January 2017 PHA evaluated exposures to VOCs based on new analyses and studies, particularly the findings from ATSDR's historical reconstruction modeling efforts.
- Several reports summarize the findings from the IRP and RCRA sites [Faye 2012; Faye et al. 2007, 2010].

2.3 *Vapor Intrusion Studies and Data*

In 2007, MCB Camp Lejeune began a base-wide vapor intrusion screening evaluation to address subsurface-to-indoor air vapor intrusion exposures. The firm CH2M has been conducting this evaluation under contract. CH2M's 2009, 2011, and 2013 reports summarize the findings of their investigations [CH2M 2009, 2011, 2013]. Investigations are ongoing.

CH2M's work focused on identifying the potential for vapor intrusion within occupied buildings located within 100 feet (ft) of VOC shallow groundwater contamination [CH2M 2008]. CH2M is using a phased approach consistent with guidelines in the Department of Defense Vapor Intrusion Handbook [DOD 2009], Interstate Technology & Regulatory Council guidelines [ITRC 2007, 2014], and USEPA vapor intrusion guidance documents [USEPA 2002, 2015].

CH2M focused their evaluation on six primary areas: Mainside, Hadnot Point, Marine Corps Air Station New River, Courthouse Bay, Camp Geiger, and Tarawa Terrace. VOC subsurface contamination exists in each of these areas, some of which are being actively remediated. The investigation and cleanup of these releases are being managed under several different programs, including the IRP, RCRA, and Underground Storage Tank (UST) program.

Figure 1A, Appendix A, shows CH2M's vapor evaluation approach. CH2M used the following process to identify buildings of concern and collect sampling data [CH2M 2008]:

1. Nonsite-specific groundwater contaminant screening levels were used to identify an initial list of 168 potential buildings of concern. Open and non-occupied structures were not included in the building screening process.
2. The list was narrowed to 50 buildings of potential concern by developing site-specific screening levels based on building surveys and use of the Johnson and Ettinger (J&E) vapor intrusion screening model. A phased field investigation was conducted to assess the potential for VI at these 50 buildings.

As reported by CH2M [2009], Phase I field activities primarily included groundwater sampling from the top of the water table and co-located soil vapor sampling adjacent to the 50 buildings. Indoor air and subslab soil gas sampling was conducted at buildings near air or biosparge remediation systems and where non-aqueous phase liquids (NAPLs) had been previously identified [CH2M 2009]. Based on the comparison of the Phase I sampling data to the generic screening levels, Phase II included additional data collection at 28 buildings, including five buildings at Hadnot Point with existing active subslab depressurization systems. Phase II field activities included indoor and outdoor air and subslab sampling and detailed building surveys. Pressure differential monitoring and groundwater sampling were also conducted at the five Hadnot Point buildings [CH2M 2009]. Phase III field activities primarily included interior sampling (i.e., indoor air and subslab soil gas sampling) [CH2M 2011].

Overall, CH2M vapor intrusion studies produced indoor air, soil gas, and shallow groundwater monitoring data. Based on an evaluation of these data and other studies, vapor intrusion mitigation systems were installed and are operating in 21 buildings and three buildings currently under construction are having a system installed as a precautionary measure[2]. The Department of Navy has also commissioned ongoing performance monitoring to make sure those systems are effective in these buildings [CH2M 2013]. The other buildings were 1) identified for additional sampling activities to continue assessing the vapor intrusion pathway or 2) identified as not posing a current significant vapor intrusion pathway [CH2M Hill 2009, 2011]. ATSDR received the reports and data produced from these studies.

The available studies and indoor air sampling data have several limitations, including the following:

- CH2M began collecting air samples in 2008. By this time, extensive groundwater remediation had occurred. Consequently, vapor intrusion and indoor air contaminant concentrations may have been lower than levels before groundwater remediation [Faye et al. 2012]. Therefore, indoor air measurements from the CH2M VI studies for these buildings may not represent historical, long-term concentrations.
- CH2M included several sample locations and periods for most of the buildings sampled. The numbers of samples taken were consistent with guidance and best practices in effect at the time they were collected[3]. Even so, there may not be enough samples to generate representative averages for all seasons or locations within each building.
- CH2M did not include buildings that were unoccupied at the time of its VI studies.

3. ATSDR Vapor Intrusion Evaluation Procedure

Chemicals in indoor air might be harmful if inhaled at concentrations high enough to be associated with health effects. The main objective of ATSDR's planned VI PHA is to evaluate the public health implications of potential exposures to current and historical indoor air contaminants that may be associated with vapor intrusion from underlying areas of groundwater contamination that may currently be entering or have seeped into MCB Camp Lejeune buildings.

To date, ATSDR has identified and organized approximately 23,000 historical documents and reports containing data of interest, as well as electronic files containing environmental data from MCB Camp

[2] Vapor intrusion mitigation systems were installed in eight buildings (3, 3B, 37, 43, 1115, 1005, 902, and LCH4007) as a result of CH2M VI studies. Vapor intrusion mitigation systems were installed because of remediation activities associated with a petroleum corrective action site in six buildings (i.e., 1101, 1108, 1200, 1201, 1202, and 1301). The building 1101 system was installed in 2000 and upgraded in 2006. The other five were installed in 2006 as a preventative measure associated with remediation activities. Six buildings (G484, G773, LCH4014, WC500, WC504, and WC510) had systems installed as a precautionary measure and one building (1068) based on a 2011 odor complaint. Three buildings currently under construction are having a system installed as a precautionary measure.

[3] Mitigation systems were installed proactively in some cases even where screening levels were not exceeded.

Lejeune and its contractors. Environmental data include indoor air, soil gas, and shallow groundwater sampling data relevant to the VI evaluation. Because outdoor air contamination can contribute to indoor air contamination, outdoor air data will be used, when available, to assist ATSDR with understanding the potential for VI in particular buildings[4]. Development of the VI PHA will follow standard procedures outlined in the *ATSDR Public Health Assessment Guidance Manual* [ATSDR 2005] and the technical supplement *Evaluating Vapor Intrusion Pathways* [ATSDR 2016].

ATSDR's planned approach to develop the VI PHA encompasses three phases of evaluation. The first phase, called "Prioritization Scheme," assists in the categorization of buildings on the base of greatest concern for potential VI impacts (see Section 3.1). The second phase, called "Refined Analyses," compiles additional sources of information that might aid in focusing ATSDR's VI evaluation (see Section 3.2). The third phase, called "Data Evaluation," is a public health evaluation of indoor air for buildings with the potential for VI risk (see Section 3.3). Throughout the process, ATSDR will conduct exploratory data analysis to help us understand the data.

ATSDR's planned VI investigation differs from the current VI work CH2M is conducting on behalf of MCB Camp Lejeune in several respects including:

1. ATSDR's dataset includes environmental samples collected from the 1980s through 2013. CH2M used environmental samples collected from September 2002 to September 2007 to determine buildings with the greatest potential for VI.
2. ATSDR will consider past, current, and future exposures, while CH2M is considering only current and future exposures. ATSDR's analyses will include demolished buildings and currently unoccupied buildings, which are not included in CH2M analyses of only occupied buildings. Note, the historic information about demolished buildings is not complete. ATSDR will use available information about demolished buildings while acknowledging that there are likely buildings that existed in the past that are not found in the currently available databases.
3. CH2M and ATSDR are not using the same procedures to identify buildings of interest. For example,
    a. CH2M initially screened only groundwater data to identify constituents of potential concern (COPCs) [CH2M 2008]. COPCs were identified by CH2M as VOCs detected most frequently in groundwater and with the greatest maximum detections above the screening levels within each area. Although the initial screening process for buildings did rely on a short list of COPCs, samples collected as part of the CH2M evaluation were analyzed and reviewed for a full list of VOCs. ATSDR will initially screen shallow groundwater, indoor air, and soil gas VOC sampling data for the full list of VOCs.
    b. CH2M conducted a risk evaluation to determine which buildings had the greatest potential for VI. This included running the J&E model and developing area-specific

[4] For example, if outdoor air contaminant concentrations are greater than those in indoor air, the outdoor air then needs to be considered as a source of any indoor air contamination, in additional to any potential indoor air sources and vapor intrusion that may have been identified.

screening levels for the COPCs for both industrial and residential scenarios (see Figure 1A, Appendix A). ATSDR will not run the J&E model as part of the screening approach[5]. Instead, ATSDR is using a Prioritization Scheme (discussed in Section 3.1) and Refined Analyses (discussed in Section 3.2) to determine areas of interest on the base potentially impacted by vapor intrusion.

3.1. *Prioritization Scheme*

ATSDR developed a site-specific Prioritization Scheme that accounts for various VI factors to assist the agency in focusing its evaluation on areas of the base of greatest concern for potential VI impacts. Given the size of the base, it is not feasible for ATSDR to perform separate VI evaluations on each of the approximately 14,000 buildings and other structures throughout MCB Camp Lejeune. ATSDR also notes that petroleum products can attenuate within shorter distances when aerobic conditions support biodegradation, but the planned Prioritization Scheme will use the assumption of no biodegradation[6]. To ensure ATSDR is timely in its VI evaluation and protective of public health, the VI PHA will place a higher importance on current exposures, although the agency will consider past exposures as data availability and resources allow.

The site-specific Prioritization Scheme will identify the buildings of greatest concern for vapor intrusion based on information currently contained in ATSDR's vapor intrusion database (VI database), which is the electronic repository of data and information to be used to develop the VI PHA. The Prioritization Scheme identifies buildings of interest using two sets of criteria. The first set of criteria addresses building-specific factors like use and size for each structure on the base (see Table 2B, Appendix B). ATSDR will present the building-specific factor results in the first row of Table 8B, Appendix B.

The second set of criteria address factors specifically related to the sampling data, such as magnitude of contaminant concentrations and frequency of detections (see Tables 3B–7B, Appendix B). Tables 3B-7B are read from left to right, then top to bottom. ATSDR will assign points to each structure in the VI database using the criteria listed in these tables. ATSDR will only add points once for each row (i.e., if criteria are met for 2 points and 1 point in the same row, the agency will only add 2 points to the total for that row, not 3 points). For each contaminant, the agency will add together the points collected from each table and mark the points for that building in the "Factor Analysis Results" section of Table 8B, Appendix B.

ATSDR's Geospatial Research, Analysis, and Services Program (GRASP) will develop a computer application to compile data from the VI database to complete the charts in the Prioritization Scheme. Figures 2A, 3A, and 4A, Appendix A, show how the pieces of the application will fit together. Once this computer application is completed, ATSDR will perform sensitivity analyses on several of the key application parameters to assess their effect on the final outcome. After performing the sensitivity

[5] ATSDR intends to use the J&E model to estimate reasonable ranges of attenuation factors based on a series of site-specific scenarios (as part of our estimation of past indoor air concentrations in Section 3.3.1).

[6] Vertical soil gas profiling of petroleum vapors is necessary to confirm aerobic biodegradation, but the data can be difficult to evaluate. A variety of site-specific conditions (e.g., large building foundations and paved surfaces) can inhibit the supply of oxygen and the reaction [ATSDR 2016].

analyses, ATSDR may modify the values of parameters and the points assigned to factors so that the agency can focus its investigation on those areas most likely to be at risk currently for VI.

To determine each building's potential VI risk, ATSDR will consider the scores for each contaminant in each building along with the building-specific factors. Based on ATSDR's technical expertise and professional judgement, the VI risk for each building will be designated as "high potential VI risk," "medium potential VI risk," "low potential VI risk," "no apparent VI risk," and "unknown VI risk." For the Prioritization Scheme, the categories are defined as:

- ***High potential VI risk*** – further assessment is supported by lines of evidence indicating the greatest potential for VI risk
- ***Medium potential VI risk*** – further assessment is supported by lines of evidence indicating a potential for VI risk
- ***Low potential VI risk*** – further assessment is supported by lines of evidence if resources allow or if sensitive populations are present
- ***No apparent VI risk*** – further assessment is not supported by lines of evidence
- ***Unknown VI risk*** – no sampling data or information are available to indicate VI potential.

Overall, the Prioritization Scheme includes primary tasks such as development of the VI database. The following text provides additional details about these tasks.

3.1.1. Measured Data

As a first step in the PHA process, ATSDR developed the MCB Camp Lejeune VI database by searching documents for historical indoor air, outdoor air, soil gas, and shallow groundwater sampling data and extracting records through 2013. ATSDR also received a series of Access and Excel files containing environmental data from MCB Camp Lejeune and its contractors. The largest dataset in the electronic databases came from CH2M, which contained more than 1.5 million records of contaminant concentrations.

Specific tasks (completed):

- Searched pre-2014 site documents focusing on those with indoor air, outdoor air, soil gas, and shallow groundwater measurements and extracted environmental chemical measurements and other relevant information into the MCB Camp Lejeune VI database[7].
- Incorporated electronic Access and Excel files containing shallow groundwater, indoor air, outdoor air, and soil gas sampling data from Camp Lejeune and its contractors into the VI database.

[7] Data were not incorporated from within former building 25 in Site 88 because there were significant indoor contaminant sources, but data were incorporated in the areas surrounding building 25. Building 25 operated as a dry cleaning facility beginning in the 1940s, ceased operation in January 2004, and was demolished to slab in August 2004 [CH2M 2008].

- Compiled relevant data through queries of the VI database to identify all shallow groundwater, indoor air, outdoor air, and soil gas sampling data. Each of these terms was defined as follows:
    - _Shallow Groundwater_: Any groundwater sample taken from a depth less than 15 ft below ground surface (bgs). In addition, if a sample came from a well screened between 15–25 ft and the water level within the well was within 15 ft of the ground surface, that sample was also designated as shallow groundwater. ATSDR did not include groundwater samples screened from deeper than 25 ft as shallow groundwater[8].

      For groundwater data with no depth information provided (i.e., collected at an unspecified depth), ATSDR classified these data as shallow groundwater if

        - the source document described the groundwater sample as "shallow groundwater."
        - the sample ID matched another sample ID in the VI database that was previously identified as "shallow groundwater."
    - _Indoor Air_: Any data referred to as "indoor air" or "crawlspace air" in the source documents. For air data with no further information regarding the type of air sample collected, ATSDR compiled these data as indoor air if the sample location appeared to be within a building footprint.
    - _Outdoor Air_: Any data referred to in the source documents as "outdoor air" or "ambient air." "Exhaust" data and "soil vapor extraction (SVE) system" data were not included in this category.
    - _Soil Gas_: Any data referred to as "soil gas," "soil vapor," "subslab soil gas," or "vapor" within the source documents. ATSDR did not compile data classified as "air sparging/soil vapor" and "SVE system" as soil gas.

3.1.2. Simulated Data

To supplement the measured data described in Section 3.1.1, ATSDR will compile simulated groundwater level and contaminant concentration data from multiple models developed to support the agency's historical reconstruction modeling of VOCs in the Hadnot Point Industrial Area (HPIA) and landfill area. Groundwater data previously modeled by the Georgia Institute of Technology (GA Tech) for VOCs for the HPIA will also be compiled. With regard to the simulated data, results were available for a variety of time periods and contaminants; the agency compiled simulated results that were readily available.

For modeling purposes, the simulated results for groundwater represent a cube of groundwater with variable heights (or distance below the ground surface). For the models, the simulated contaminant

[8] The surficial aquifer thickness and depth to groundwater vary across the base. As reported in CH2M [2009], the depth to groundwater ranges from 0 (surface water) to 22 ft bgs. At the start of the data extraction project, ATSDR used professional judgement and choose groundwater samples screened from a depth ≤25 ft, when the water level within the well was within 15 ft of the ground surface, to be representative of shallow groundwater that may impact vapor intrusion into base buildings and incorporated those groundwater samples into the VI database.

concentrations are for the center point of each grid. ATSDR expects to only use the Model Layer 1 simulated contaminant concentrations for locations that represent shallow groundwater (i.e., when the center point is ≤ 25 ft bgs). For the HPIA and landfill area, the volume of each grid cell varies from 300 ft x 300 ft x variable height to 50 ft x 50 ft x variable height. Before using these data in the VI PHA, ATSDR will also determine whether the simulated contaminant concentration data for Model Layer 1 are similar to the measured contaminant concentration data for the same locations and time frames.

Specific tasks:

- Compile ATSDR's simulated groundwater level data for the following:
  - Steady-state (predevelopment) simulated groundwater level data for the Tarawa Terrace, HPIA and landfill models.
  - Transient-state (pumping) simulated groundwater level data for Tarawa Terrace (January 1951 to December 1994), and HPIA and landfill area (January 1942 to June 2008).
- Determine whether the simulated groundwater results for each location represent shallow groundwater (i.e., if the center point of the grid is ≤ 25 ft bgs).
  - If the simulated groundwater results for the location do not represent shallow groundwater, the agency will not use that location's results in the VI PHA.
- For simulated groundwater location results that represent shallow groundwater, compile ATSDR's simulated groundwater data for the following:
  - TCE and benzene monthly concentrations for the HPIA from January 1942 to June 2008.
  - PCE and TCE monthly concentrations for the landfill area from January 1942 to June 2008.
- For simulated groundwater location results that represent shallow groundwater, compile GA Tech's simulated groundwater data for the following:
  - TCE monthly concentrations for the HPIA for January 1951, January 1968, November 1984, and June 2008.
  - TCE concentrations for the HPIA for the months of April, May, June, July, August and September for the years 1995, 1996, 1997, 2001 2002, 2003, and 2004.
- Compare the simulated shallow groundwater results for Model Layer 1 with measured shallow groundwater results for similar locations and time frames to determine how well the simulated concentrations match measured concentrations (most likely using a Kendall's Tau rank correlation coefficient, t-test, and/or Wilcoxon signed rank test.)
  - If the simulated groundwater results for Model Layer 1 are not similar to the measured shallow groundwater results, the agency will not use the simulated contaminant results in the VI PHA. That is, none of the tasks describing the simulated contaminant datasets will be completed.

3.1.3. Building-specific Information

ATSDR will compile information contained in the VI database for buildings such as building use, status, and size. The agency will also use the sampling data in the VI database to compile relevant information related to contamination near buildings. All buildings, including historical buildings that have since been demolished, will be evaluated as data allow.

Specific tasks:

- Compile building use information such as workplace, warehouse, storage, school, residence, health care, or unknown. Workplace is defined as buildings on the base with an occupational setting. Warehouse and storage use were noted for many buildings so ATSDR decided to include them as separate categories from the general "workplace" category. Residence refers to places where people reside and sleep, including homes and barracks. Health care includes hospitals and medical care facilities. In addition, ATSDR assumes specific types of building use imply the presence of susceptible populations, such as children in schools. Note, buildings with other uses such as a "latrine", which are unlikely to remain occupied by the same person, will receive a use categorized as "short-duration use".
- Collect information on the building status such as whether the building exists or was demolished.
- Using the building footprint, record the approximate size of the building footprint.
- For all buildings in the VI database, both past and present, map a 100 ft buffer around the building footprint [ATSDR 2016]. Using this 100 ft buffer:
  - Record whether each building is above or within 100 ft of free product[9] in the groundwater for the HPIA.
  - Record whether each building is above or within 100 ft of a shallow groundwater plume[10].
  - For four time periods of measured data (1980s, 1990s, 2000–2007, 2008–2013), compile information on how many shallow groundwater and soil gas samples were collected

[9] Previous ATSDR and GA Tech modeling efforts included collection and organization of free product measurements from a variety of historical reports in the HPIA. Free product refers to fuel-related light non-aqueous phase liquids (LNAPL) that are at the groundwater table. There are three locations within the HPIA that had significant subsurface LNAPL contamination: the Hadnot Point Fuel Farm (HPFF), Building 1115 area, and Building 1613 area. The thickness results are point data centered on a 3 ft × 3 ft grid, with simulated thickness values in meters and in feet. The saturation results are point data centered on a 25 ft × 25 ft grid, with simulated saturation values in percent ranging from 0 to 0.208 (0 to 20.8%). The upper value of ~20% indicates that LNAPL occupies most of the pore spaces between soil grains.

[10] Preliminary information ATSDR received marked shallow and surficial groundwater plumes on the base. This information will be used during the sensitivity analyses (see Section 3.1.6) and not as a part of the Prioritization Scheme factor analysis charts.

within 100 ft of each building[11], and how many indoor air samples were collected from inside each building.

- For the four time periods of measured data, compile the rate of detection for shallow groundwater and soil gas within 100 ft of each building, and the rate of detection for indoor air inside each building.

3.1.4. Comparison Values

ATSDR will compile available residential air health-based comparison values (CVs) for the 162 compounds thought to be sufficiently volatile to potentially pose a health risk via vapor intrusion (see Table 1B, Appendix B) [ATSDR 2016]. ATSDR and USEPA have residential health-based air CVs for many of these 162 compounds that can be used to initially screen indoor air data to identify which contaminants are of potential concern (see Table 9B, Appendix B) [ATSDR 2018, USEPA 2017]. Health-based CVs are estimates of daily human exposures to chemicals that are not likely to result in harmful health effects over a specified exposure duration. ATSDR has developed CVs for specific media (e.g., air, water, and soil), which can be based on cancer and/or noncancer health effects.

ATSDR air CVs are protective of residential, 24-hour exposures and will be used to evaluate the indoor air data. ATSDR has not developed health-based CVs specifically evaluating the potential for vapor intrusion from groundwater and soil gas. Instead, ATSDR uses the residential air CVs to calculate general, health-protective (i.e., not site-specific) groundwater and soil gas contaminant concentrations, called vapor intrusion comparison values (VICVs) (see Table 10B, Appendix B).

Specific tasks:

- Compile available short-term and long-term[12] residential air CVs for each contaminant that will be used to screen the indoor air data. Note those contaminants with no CVs.
- Use the available short-term and long-term residential air CVs to calculate each contaminant's general groundwater VICVs using the formula: Groundwater VICV = Air CV / [(Henry's law constant × USEPA groundwater attenuation factor × unit conversion factor)], where the USEPA groundwater attenuation factor (AF_{USEPA}) is 0.001 and the unit conversion factor is 1,000 liters per cubic meter (L/m^3) [ATSDR 2016].
- Use the available short-term and long-term residential air CVs to calculate each contaminant's general soil gas VICVs using the formula: Soil Gas VICV = Air CV / USEPA soil gas attenuation factor, where the USEPA soil gas attenuation factor is 0.03 [ATSDR 2016].

3.1.5. Data Screening

ATSDR will compile data and calculate initial summary statistics for the measured data in the VI database, such as mean and 95% upper confidence levels (UCL) of the mean contaminant

[11] Samples collected under building footprints, such as sub-slab soil gas samples, are considered to be "within 100 ft of the building."

[12] In general, short-term exposures refer to chemical exposures that may last only a few minutes or a few hours, to those that may last for days, weeks, or even a few months. Long-term exposures refer to chemical exposures lasting a year or more.

concentrations. For the ATSDR simulated data, monthly contaminant concentrations will be averaged over a rolling 3-year period[13] for each location. For the GA Tech simulated data, averages[14] will be calculated for the 1990s and 2000s timeframes. The agency will use the summary statistics to screen available indoor air, soil gas, and shallow groundwater measured data, as well as simulated estimates of contaminants in shallow groundwater, against CVs and VICVs. ATSDR's screening analysis process enables agency staff to sort through data in a consistent manner.

Health-based air CVs, as well as all other health-based screening criteria like VICVs, are conservative levels of protection—they are not thresholds of toxicity. *Although concentrations at or below a CV represent low or no risk, concentrations above a CV are not necessarily harmful.* To ensure that they will protect even the most sensitive populations (e.g., children, women of childbearing age), CVs are designed intentionally to be much lower, usually by two or three orders of magnitude[15], than the corresponding no-observed-adverse-effect-levels (NOAELs) or lowest-observed-adverse-effect-levels (LOAELs) on which the CVs are based. Most NOAELs and LOAELs are established in laboratory animals; relatively few are derived from epidemiologic (i.e., chiefly worker) studies. All ATSDR health-based CVs are non-regulatory—they are for screening purposes only. *The exceedance of a CV does not indicate health effects are likely, but rather that the exposure warrants further assessment to determine its potential to impact health.*

Specific tasks:

- Identify the available measured soil gas and shallow groundwater data within 100 ft of a building, and the available measured indoor air data inside a building, for screening purposes on a building-by-building basis for each contaminant.
    - For buildings identified as school, residence, health care, or unknown ATSDR will screen indoor air measured data "as is" because the agency's residential health-based CVs are based on continuous exposure.
    - For buildings identified as a workplace, warehouse, storage, or short-term use, there is a less than 24-hour exposure (i.e. non-continuous, occupational exposure). The measured indoor air concentrations will be modified to account for a less than 24-hour exposure; specifically, the measured indoor air concentrations will be time-adjusted for a 10-hour workplace exposure[16] [ATSDR 2016]. For example, a concentration of 2 micrograms per

[13] Using 3 years is consistent with the ATSDR health studies' exposure duration as well as the exposure duration used in the drinking water public health assessment.

[14] The GA Tech simulated data available to ATSDR include monthly concentrations for six consecutive months for the years 1995, 1996, 1997, 2001 2002, 2003, and 2004; therefore, a rolling yearly average cannot be calculated.

[15] "Order of magnitude" refers to an estimate of size or magnitude expressed as a power of ten. An increase of one order of magnitude is the same as multiplying a quantity by 10, an increase of two orders of magnitude equals multiplication by 100, an increase of three orders of magnitude is equivalent to multiplying by 1000, and so on. Likewise, a decrease of one order of magnitude is the same as multiplying a quantity by 0.1 (or dividing by 10), a decrease of two orders of magnitude is the equivalent of multiplying by 0.01 (or dividing by 100), and so on.

[16] At this time, ATSDR is proposing a time-adjustment for a 10-hour workplace exposure, which is consistent with the agency's VI guidance. However, ATSDR will work with Camp Lejeune and the CAP to determine whether a different time-adjustment is more appropriate that accounts for site-specific worker exposures.

cubic meter (μg/m^3) that is time-adjusted for a 10-hour workplace exposure would be modified by a factor of 0.41 (or 10 hours/24 hours) to calculate an air concentration of 0.82 μg/m^3. For the VI PHA, this 10-hour workplace adjustment will be used for evaluating acute/short-term exposures. For chronic/long-term exposures, the measured indoor air concentrations will be time-adjusted for a 10-hour, 5-day workplace exposure, which is a modifying factor of 0.30 (or 10 hours/24 hours × 5 days/7days). These "adjusted-measurements" for workplace buildings will be used for the remainder of the VI PHA evaluation (e.g., in the next task, the mean will be calculated with the adjusted-measurement concentrations for workplace indoor air).

    - All shallow groundwater and soil gas data (measured and simulated) will be screened "as is" regardless of the building use near the location of measurements.

- For the measured data, calculate mean contaminant concentrations, 95% UCL of the mean[17], and coefficients of variation on a building-by-building basis for each contaminant.
    - For each contaminant sampled from shallow groundwater wells within 100 ft of a building, the agency will calculate mean contaminant concentrations for four time periods of measured data (1980s, 1990s, 2000–2007, 2008–2013). The agency prefers a minimum of 8 samples. If there are fewer than 8 samples for a given time period, ATSDR will not calculate a mean; the agency will also not calculate a mean if there are fewer than 4 detected samples or if more than 80% of the samples are nondetects. The contaminant's maximum value will be used in place of the mean value in these instances. Note, based on ATSDR's preliminary review of the available data for shallow groundwater, indoor air, and soil gas, many of the contaminants do not meet these criteria within 100 ft of the buildings during any of the four time periods.
    - The number of samples in each time period will also determine the preferred statistical approach to calculating the 95% UCL. For 8 to 19 samples, ATSDR will determine whether the data best fit a normal distribution, a lognormal distribution, or a gamma distribution and calculate the 95% UCL using the recommended parametric statistical approach. For 20 or more samples, ATSDR will calculate the 95% UCL using non-parametric "bootstrapping" techniques.
        - However, the contaminant's maximum value will be used in place of the 95% UCL value if any or all of these instances are true:
            - There are fewer than 8 samples for a given time period.
            - There are fewer than 4 detected samples for a given time period.
            - There are more than 80 percent nondetects for a given time period.

[17] ATSDR expects guidance for estimating exposure point concentrations, including calculating means and 95% UCLs, to be released soon. Although the agency cannot share the draft guidance at this time, the VI PHA will incorporate this guidance in its evaluation.

  - ATSDR will calculate the coefficient of variation for each contaminant for each time period. A large coefficient of variation (greater than 100% or 200%) may be indicative of significant changes in contaminant concentrations across either space or time.
  - ATSDR will follow the same procedures for calculating means, 95% UCLs, and coefficients of variation for
    - soil gas contaminant concentrations within 100 ft of each building.
    - indoor air contaminant concentrations collected inside buildings with a use designated as school, residence, health care, or unknown.
    - indoor air adjusted-measurement contaminant concentrations collected inside buildings with a use designated as workplace, warehouse, storage, or short-duration use.
- For the ATSDR simulated data[18], calculate monthly concentrations as 3-year rolling averages for each shallow groundwater contaminant under and within 100 ft of a building footprint on a building-by-building basis.
  - For example, the monthly groundwater contaminant concentration for July 1984 is the average of the monthly simulated concentrations for the 3 years that follow July 1984, or the average from July 1984 to June 1987.
  - When a building's footprint is above or within 100 ft of more than one grid point, the groundwater contaminant's highest monthly 3-year rolling average will be used as the monthly 3-year rolling average for the building in the Prioritization Scheme.
- For the GA Tech simulated data[18], calculate averages for each groundwater contaminant under and within 100 ft of a building footprint on a building-by-building basis.
  - When a building's footprint is above or within 100 ft of more than one grid point, the groundwater contaminant's highest average will be used as the time frame's average for the building in the Prioritization Scheme.
- Screen the shallow groundwater, soil gas, and indoor air data on a building-by-building basis.
  - For each contaminant measured in shallow groundwater within 100 ft of a building,
    - ATSDR will determine whether the measured maximum contaminant level exceeds each contaminant's *short-term general groundwater VICV*, and if so, the agency will record the magnitude of the greatest exceedance. The agency will follow the same screening procedure for soil gas contaminant concentrations within 100 ft of each building and for indoor air contaminant concentrations inside each building.

[18] The location must represent shallow groundwater (i.e., the center point of the grid must be ≤ 25 ft bgs).

- ATSDR will also note if there are a significant number of data points where the analytical reporting limit is greater than the groundwater and soil gas VICVs, and air CVs.

▪ ATSDR will determine whether the highest 95% UCL contaminant levels[19] exceed each contaminant's *long-term general groundwater VICV*, and if so, the agency will record the magnitude and year range of the greatest exceedance. The agency will follow the same screening procedure for the 95% UCLs for soil gas measurements within 100 ft of each building and indoor air measurements inside each building.

- However, 95% UCL contaminant levels for TCE would not be appropriate to evaluate pregnant women's exposures (as short-term monthly peaks may not be accounted for) because of concerns associated with fetal heart impacts occurring in as little as 3 weeks of exposure. Therefore, for screening TCE in shallow groundwater, soil gas, and indoor air, ATSDR will determine whether the measured maximum TCE level is above TCE's long-term VICVs and CV.

o For each simulated groundwater contaminant at grid point locations[20] under or within 100 ft of a building footprint,

▪ ATSDR will determine whether the maximum monthly contaminant level exceeds each contaminant's short-term general groundwater VICVs. If so, the agency will record the magnitude of the greatest exceedance.

▪ ATSDR will determine whether the highest average contaminant level[21] exceeds each contaminant's long-term general groundwater VICVs. If so, the agency will record the magnitude and year of the greatest exceedance.

- Note that for TCE, ATSDR will determine whether the simulated maximum TCE levels exceed TCE long-term general groundwater VICVs.

o Those contaminants with no groundwater and soil gas VICVs, and no air CVs, will be reviewed on a contaminant-by-contaminant basis by ATSDR toxicologists to determine whether the contaminant will be retained for further evaluation.

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[19] For those instances where ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant's maximum value will be used in place of the 95% UCL value for long-term screening.

[20] The location must represent shallow groundwater (i.e., the center point of the grid must be ≤ 25 ft bgs).

[21] For the GA Tech simulated results, ATSDR will note the time frame with the highest average (i.e., 1990s or 2000s). For the ATSDR simulated results, the agency will note each year's highest monthly 3-year rolling average. Also, for those instances where ATSDR was not able to calculate an average for the simulated data, the contaminant's maximum value will be used in place of the average value for long term screening.

- Of the 47 contaminants with no VICV and no CV, ATSDR found that 30 contaminants had a sample collection location inside or within 100 ft from a building.
- For those 30 contaminants, ATSDR will review how often the contaminant was detected in each environmental media, the range of contaminant concentrations in each media, and the contaminant's properties such as Henry's law constant to determine volatility of each contaminant. The agency will also check whether there are available comparison values from other entities such as state agencies. ATSDR might also consider using software that assists with finding structural similarities between chemicals to find a surrogate contaminant to help in the evaluation, if needed. Note, these 30 contaminants with no CVs will be reviewed outside the Prioritization Scheme; if any of the contaminants are found to be a potential VI risk, the buildings within 100 ft will be included as part of the building-specific public health evaluations in Section 3.3.2.

3.1.6. Sensitivity Analyses

As stated previously, ATSDR will create a computer application from the Prioritization Scheme that compiles information currently contained in the VI database. Once the application is complete, ATSDR will perform sensitivity analyses on the application parameters. The main goal of the sensitivity analyses will be to gain insight into which application assumptions are critical. The process involves various ways of changing application input values to see the effect on the output value. Output results will also be compared with datasets of known and suspected shallow groundwater plumes for the base and three free product areas within the HPIA. Comparison with these datasets will ensure that the computer application adequately identifies areas of contamination and will allow for a more objective analysis of the validity of each set of parameters used in the sensitivity analyses. Based on the results of the sensitivity analyses, ATSDR may modify its analysis so that the agency can focus its investigation on those areas most likely to be at risk currently for VI.

Specific tasks:

- Changing the time periods for calculations (e.g., 1980–1984, 1985–1989, 1990–1995, etc.).
- Changing values in the tables including
  - The distance in Tables 5B and 6B (e.g., within 25 ft, 50 ft, and 75 ft of the building).
  - The coefficient of variation in Tables 5B–7B (e.g., 400% and 50%).
- Changing the number of points assigned to each factor in each table including
  - Increasing the point values in columns in Tables 5B, 6B, and 7B (e.g., from 2 to 4 and 1 to 2 for all three tables).
  - Increasing the point values in columns one table at a time (e.g., from 2 to 4 and 1 to 2 in only Table 7B).

  - Increasing the point values of specific rows in Tables 5B, 6B, and 7B (e.g., from 2 to 4 and 1 to 2 for just the "Magnitude of exceedance" row in these tables).

- Changing the shallow groundwater and soil gas attenuation factor for comparison value calculations to assume no attenuation is occurring (i.e., attenuation factor equals 1).
- Running the computer application with measured indoor air, shallow groundwater and soil gas data only (i.e., do not include shallow groundwater simulated data).
- Running the computer application comparing the maximum contaminant levels with each contaminant's long-term CVs and VICVs, as described in ATSDR's guidance manual [ATSDR 2005].
- Evaluating the output results for each sensitivity analysis compared to the original output results, as well as shallow groundwater plume and free product locations to ensure that known and suspected areas of contamination are adequately reflected in the computer application output.

3.2. ***Refined Analyses***

ATSDR's Prioritization Scheme uses information currently in the VI database to assist the agency in focusing its evaluation on buildings of greatest concern for potential VI impacts. However, there are additional sources of information that might aid in focusing ATSDR's VI evaluation, such as buildings CH2M is focusing on as well as other information that has not yet been integrated into the agency's VI database.

3.2.1. CH2M Building List

As stated previously, ATSDR's planned VI investigation differs from the current VI work CH2M is conducting on behalf of MCB Camp Lejeune. Because CH2M used a different approach to determine which buildings had the greatest potential for VI, ATSDR will compare the buildings identified by its Prioritization Scheme to the building list developed by CH2M to determine whether CH2M identified any buildings that ATSDR did not; if so, ATSDR will evaluate whether these CH2M buildings should be included in the Prioritizations Scheme as having the potential for VI. Note that

- CH2M initially included buildings within 100 ft of groundwater with contaminant concentrations above groundwater screening values [CH2M 2008]. The groundwater screening values used by CH2M are based on concentrations likely to produce indoor air contaminant concentrations above the USEPA Regional Screening Levels for both residential and industrial exposures [USEPA 2008]. ATSDR uses residential health-based CVs.
- CH2M evaluated preferential pathways for vapor intrusion that were limited to areas with utilities connecting high subsurface source areas to buildings [CH2M 2008]. CH2M also retained buildings located within 100 ft of where non-aqueous phase liquids (NAPLs) had been previously identified as well as buildings located within 100 ft of remediation systems such as air or biosparge systems that can create pressure gradients [CH2M 2008].
- No buildings with sensitive populations, such as schools and daycare centers, have currently been identified by CH2M as posing a potential for vapor intrusion.

3.2.2. Area Investigation

To further focus the VI analysis, ATSDR's GRASP will explore various geographic information system (GIS) techniques, such as heat and thematic maps, to visualize areas of the base containing buildings with a higher VI risk. ATSDR may also consider additional information in the VI database as part of its GIS visual exploration of each area including:

- If there is an estimated shallow groundwater plume in the area
  - Whether the plume source is chlorinated solvents and/or petroleum hydrocarbon, or unknown.
  - Whether the plume source is a large release volume (e.g., years of industrial releases), a small release volume (e.g., short-term tank leak), or unknown.
  - Whether the plume source is flowing towards the buildings in the area or away from them, which is complicated because flow direction can be different for steady-state conditions and various water supply well pumping schedules.
- If the time periods with highest chemical concentrations in one environmental medium coincide with the time periods with the highest concentrations in the other environmental media (i.e., soil gas and indoor air, shallow groundwater and soil gas, shallow groundwater and indoor air, and all three media together).
- If the contamination was detected in indoor air, but was either not detected in shallow groundwater and soil gas or was detected at much lower concentrations in these media, and vice versa.
- If an adequate number of soil gas sampling results are available to separate the data by depth.
- If there are underground storage tanks (USTs), and/or potential pathways such as underground pipelines (e.g., sewer, water) in the area.
- If there is a significant indoor contaminant source in specific buildings.
- If there are air and/or biosparge remediation systems in the area.
- If other information such as average depth to groundwater and groundwater well screening intervals are known for the area.

Some of this information is readily available for portions of the base, but not yet fully integrated into the agency's VI database. To the extent these data are available, ATSDR will consider them in the VI evaluation.

Specific tasks:

- Incorporate available information into the VI database including information on contamination sources and plumes, groundwater flow direction, USTs, and potential underground pathways.
- Conduct exploratory data analysis, including the creation of GIS maps of the base, to determine areas where buildings with "high potential VI risk," "medium potential VI risk," and "low

potential VI risk" are located; also, create labels (i.e., Area 1, Area 2, etc.) encompassing buildings in the same area.

- For each area, overlay any additional information (e.g., groundwater flow direction, underground utility lines) on the GIS maps.
- Use the GIS maps and additional information to visualize areas of the base containing buildings with a higher VI risk.
    - Visualizing the information will help ATSDR prioritize areas of the base for evaluation.
    - Buildings with "no apparent VI risk" and "unknown VI risk" from Section 3.1 will not be evaluated further by ATSDR unless those buildings were identified in an area with potential VI risk based on groundwater flow direction, potential underground pathways, and/or nearby USTs.

3.3. *Data Evaluation*

ATSDR's Prioritization Scheme will assist the agency in initially designating buildings on the base as "high potential VI risk," "medium potential VI risk," "low potential VI risk," "no apparent VI risk," and "unknown VI risk." Then, ATSDR's area investigation will help to visualize areas of the base containing buildings with a higher VI risk. Next, ATSDR will explore the representativeness of the data and estimate historical indoor air exposures for its data evaluation.

After estimating the historic indoor air contaminant concentrations, ATSDR will use its health assessment procedures to evaluate the public health implications of potential past and current indoor air exposures to building occupants. ATSDR will focus on areas of the base with buildings having the highest potential for VI risk first, working towards areas with buildings having low potential VI risk, thereby addressing as many buildings as feasible.

3.3.1. Estimate Historical Indoor Air Exposures

For buildings with measured groundwater data allowing for the calculation of a 95% UCL value, ATSDR will first examine whether the shallow groundwater data are representative over space and time. If so, for these buildings and for buildings with simulated groundwater concentrations, ATSDR will estimate indoor air contaminant concentrations using groundwater-to-air attenuation factors (AFs). Unlike groundwater data, there are very limited soil gas data available to assist with historical indoor air exposure estimates. Because there are so few samples, ATSDR does not expect the limited soil gas data from the past to be representative over space and time.

The USEPA general groundwater attenuation factor (AF_{USEPA}) will be used for estimating upper bounds air concentrations for buildings designated as school, residence, health care, or unknown. For workplace, warehouse, and storage buildings, ATSDR will use non-residential AFs. One AF that ATSDR will use was developed as part of the Navy's Environmental Sustainability Development to Integration (NESDI) project. This project included an analysis of AFs for industrial buildings on a variety of bases around the country. The NESDI project methods were generally consistent with those of the USEPA residential database and suggest an industrial building groundwater-to-air AF_{NESDI} of 0.0001 to estimate upper bound indoor air concentrations [NAVFAC 2015]. For a few non-residential buildings on the base where building-specific characteristics are known (e.g., warehouses where building heights and air exchange rates are known), ATSDR will also calculate building-specific groundwater attenuation factors (non-res AF_{gw}) (see Appendix C).

ATSDR will use these AFs to estimate building-specific indoor air concentrations for periods when groundwater contaminant concentrations are available for these buildings.

Specific tasks:

- Use professional judgement to determine whether the shallow groundwater data are representative over space and time for buildings with measured groundwater data allowing for the calculation of a 95% UCL value.
    - Check the number and placement of shallow groundwater monitoring wells surrounding the building to determine whether the data are sufficient for characterizing the spatial extent of potential groundwater contamination.
    - Check the frequency of shallow groundwater sampling measurements surrounding the building to determine whether the data adequately characterize variations that may occur over time, such as seasonal variations.
    - If shallow groundwater data are not considered representative for a building, the agency will not estimate indoor air concentrations for that building.
- Gather building-specific characteristics (i.e., building heights, construction, and air exchange rates) for those buildings with shallow groundwater data that are representative over space and time, and those buildings with simulated groundwater data.
- For buildings designated as school, residence, health care, or unknown with measured groundwater data allowing for the calculation of a 95% UCL value, estimate building-specific indoor air contaminant concentrations for available time periods (i.e., 1980s, 1990s, 2000–2007, and 2008–2013)[22] using the AF_{USEPA} as follows:
    - Indoor air contaminant estimate (IA_{95UCL}) = AF_{USEPA} × historic groundwater contaminant 95% UCL value × Henry's law constant × unit conversion factor[23]
    - Indoor air contaminant estimate (IA_{max}) = AF_{USEPA} × historic groundwater contaminant maximum detected value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{min}) = AF_{USEPA} × historic groundwater contaminant minimum detected value × Henry's law constant × unit conversion factor

[22] If the sensitivity analysis indicates changing the time periods for calculations (e.g., 1980–1984, 1985–1989, 1990–1995, etc.) is needed, those same time periods will be carried throughout ATSDR's analyses, including the estimates of building-specific indoor air contaminant concentrations.

[23] The unit conversion factor is 1,000 liters per cubic meter (L/m^3) for all the indoor air contaminant estimates.

- For buildings designated as school, residence, health care, or unknown with simulated shallow groundwater data[24], estimate building-specific indoor air contaminant concentrations for available time periods using the AF_{USEPA} as follows:
    - Indoor air contaminant estimate ($IA_{sim\text{-}ave}$) = AF_{USEPA} × historic groundwater contaminant simulated average value (i.e., ATSDR monthly 3-year rolling average groundwater concentrations) × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate ($IA_{sim\text{-}monthly}$) = AF_{USEPA} × historic groundwater contaminant simulated monthly value (i.e., ATSDR and GA Tech monthly groundwater concentrations) × Henry's law constant × unit conversion factor
- For buildings designated workplace, warehouse, or storage with measured groundwater data allowing for the calculation of a 95% UCL value, estimate building-specific indoor air contaminant concentrations for available time periods (i.e., 1980s, 1990s, 2000–2007, and 2008–2013) using the AF_{NESDI} and non-res AF_{gw} as follows:
    - Indoor air contaminant estimate (IA_{95UCL}) = AF_{NESDI} × historic groundwater contaminant 95% UCL value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{max}) = AF_{NESDI} × historic groundwater contaminant maximum detected value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{min}) = AF_{NESDI} × historic groundwater contaminant minimum detected value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{95UCL}) = non-res AF_{gw} × historic groundwater contaminant 95% UCL value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{max}) = non-res AF_{gw} × historic groundwater contaminant maximum detected value × Henry's law constant × unit conversion factor
    - Indoor air contaminant estimate (IA_{min}) = non-res AF_{gw} × historic groundwater contaminant minimum detected value × Henry's law constant × unit conversion factor
- For buildings designated workplace, warehouse, and storage with simulated shallow groundwater data[25], estimate building-specific indoor air contaminant concentrations for available time periods using the AF_{NESDI} and non-res AF_{gs} as follows:
    - Indoor air contaminant estimate ($IA_{sim\text{-}ave}$) = AF_{NESDI} × historic groundwater contaminant simulated average values (i.e., ATSDR monthly 3-year rolling average groundwater concentrations) × Henry's law constant × unit conversion factor

[24] The locations with simulated contaminant data must represent shallow groundwater (i.e., the center point of the grids must be ≤ 25 ft bgs).

[25] The locations with simulated contaminant data must represent shallow groundwater (i.e., the center point of the grids must be ≤ 25 ft bgs).

- Indoor air contaminant estimate ($IA_{sim\text{-}monthly}$) = AF_{NESDI} × historic groundwater contaminant simulated monthly value (i.e., ATSDR and GA Tech monthly groundwater concentrations) × Henry's law constant × unit conversion factor
- Indoor air contaminant estimate ($IA_{sim\text{-}ave}$) = non-res AF_{gw} × historic groundwater contaminant simulated average value (i.e., ATSDR monthly 3-year rolling average groundwater concentrations) × Henry's law constant × unit conversion factor
- Indoor air contaminant estimate ($IA_{sim\text{-}monthly}$) = non-res AF_{gw} × historic groundwater contaminant simulated monthly value (i.e., ATSDR and GA Tech monthly groundwater concentrations) × Henry's law constant × unit conversion factor

- For buildings with an average depth to groundwater of <5 ft, change the groundwater attenuation factors for the above estimated indoor air contaminant calculations to assume no attenuation is occurring (i.e., attenuation factor equals 1).
- For buildings with indoor air measurements, determine whether the estimated indoor air concentrations are similar to actual indoor air measurements, most likely using a Kendall's Tau rank correlation coefficient, t-test, and/or Wilcoxon signed rank test.
- Use the J&E model to estimate reasonable ranges of AFs based on a series of site-specific scenarios.
  - The ranges will be used to explore the upper and lower bounds of vapor intrusion using a series of building, soil, and groundwater characteristics. ATSDR can compare the measured data to simulated data to explore the uncertainty in the measured data and validate the model. ATSDR can also explore comparing the AF ranges from the J&E model to the USEPA, NESDI, and calculated AFs that will be used to estimate past indoor air concentrations.

3.3.2. Public Health Evaluation

After identifying the measured and the estimated historic indoor air contaminant concentrations in base buildings, ATSDR will use its health assessment procedures to evaluate the public health implications of potential indoor air exposures to building occupants [ATSDR 2005, 2016]. As stated previously, ATSDR will focus on areas of the base with buildings having the highest potential for VI risk first, working towards areas with buildings having lower potential VI risk, thereby addressing as many buildings as feasible.

For its PHA evaluations, ATSDR conducts a review of the supporting toxicological research to evaluate the potential for site exposures to cause harm. While the toxicity of a chemical is important, the human body's response to a chemical exposure is determined by several additional factors, including the

- Concentration (how much) of the chemical the person was potentially exposed to,
- Amount of time (how long) the person was potentially exposed, and
- Route by which the person was exposed (e.g., breathing the chemical).

Two key steps in this analysis are 1) comparing site-specific exposure level estimates with observed effect levels reported in critical studies, and 2) considering study parameters in the context of site exposures [ATSDR 2005]. This analysis requires the examination and interpretation of reliable, substance-specific health effects data and a review of epidemiologic (human) and experimental (animal) studies. Study parameters that may affect the relevance to site-specific exposures include whether the route of exposure is similar (e.g., drinking water route in the critical study versus breathing indoor air at the site) and whether the duration is similar (e.g., a few days of exposure in the critical study versus years of exposure at the site). In general, a study based on human data holds the greatest weight in describing relationships between a particular exposure and a human health effect. Fewer uncertainties arise regarding potential outcomes documented in well-designed epidemiologic (i.e., human-based) studies. Therefore, understanding the strengths and weaknesses of epidemiologic studies helps determine the suitability of a particular study in supporting and in drawing public health conclusions [ATSDR 2005].

Overall, assessing the relevance of available human and animal studies with respect to site-specific exposures requires both technical expertise and professional judgment. **Because of uncertainties regarding exposure conditions and the adverse effects associated with environmental exposure levels, definitive answers about whether health effects actually will or will not occur are not always possible.** Nevertheless, providing a framework that puts site-specific exposures and the potential for harm in perspective is possible, and it is one of the primary goals of ATSDR's public health evaluation process [ATSDR 2005].

Specific tasks:

- For contaminants exceeding health-based CVs in the highest VI potential risk areas, document contaminant-specific health effects information summarized in the respective toxicological literature. If additional contaminants exceeding health-based CVs are identified in lower VI potential risk areas, document contaminant-specific health effects information when appropriate.
- Starting with areas of the base with buildings having the highest potential for VI risk first and working towards areas with buildings having lower potential VI risk, develop building-specific conceptual models that are supported by maps, narratives, and tables. For each building,
    - Summarize building-specific information previously compiled in the VI database and maps, particularly information from Sections 3.1.3 and 3.2.2. This information includes:
        - Building use and status (currently exists/demolished)
        - Building mitigation system status (on/off)
        - Potential indoor air sources
        - Nearby USTs and/or potential underground pathways (e.g., sewer, water lines)
        - Nearby contamination sources, groundwater plumes, and depth to groundwater (if known)

        - Nearby air and/or biosparge remediation systems

- Summarize building-specific shallow groundwater, soil gas, and indoor air information previously compiled through the Prioritization Scheme and maps.
- Compile outdoor air data, if available, for the area.
- Work with MCB Camp Lejeune to verify current building occupancy, determine whether occupancy changed over time, confirm building use over time[26], and gather building floor plan, size, condition, and foundation information.
    - To the extent information is readily available, document past building occupancy, use and floor plans for unoccupied buildings and for demolished buildings.
- For each measured contaminant exceeding health-based CVs, compare the measured indoor air maximum concentrations for each time period with acute health effect levels summarized in the toxicological literature, and compare the indoor air 95% UCL concentrations for each time period with chronic health effect levels.
    - As mentioned previously in this Work Plan, for buildings identified as workplace, warehouse, or storage, there is a less than 24-hour exposure (i.e. non-continuous, occupational exposure). For comparison with acute health effect levels, the measured indoor air concentrations will be time-adjusted for a 10-hour workplace exposure (i.e., 0.41 modifying factor) and these "adjusted-measurements" for workplace buildings will be used for VI PHA evaluation. For comparison with chronic health effect levels, the measured indoor air concentrations will be time-adjusted for a 10-hour, 5-day workplace exposure (i.e., 0.30 modifying factor) and these "adjusted-measurements" for workplace buildings will be used for VI PHA evaluation. For buildings identified as school, residence, health care, or unknown, ATSDR will use the measured indoor air concentrations "as is" for VI PHA evaluation.
    - Note that for TCE in indoor air, ATSDR will compare the measured maximum levels with chronic effect levels.
- For each estimated contaminant exceeding health-based CVs, compare the estimated indoor air monthly concentration ranges with acute health effect levels, and the estimated indoor air average concentration ranges with chronic health effect levels summarized in the toxicological literature.
    - Building-specific estimated indoor air concentrations from both measured and simulated groundwater data will be evaluated by ATSDR. Note that there is a

[26] Note: ATSDR will rely on current building use unless the agency is provided records indicating past building use was different than current use.

high level of uncertainty in the estimated indoor air contaminant concentrations.

- Note that for TCE in indoor air, ATSDR will compare the simulated maximum levels with chronic effect levels.

- Request the latest indoor air monitoring data for buildings with vapor intrusion mitigation systems[27] and determine whether any contaminants are above health-based CVs. If so, compare the measured indoor air maximum concentrations with acute health effect levels summarized in the toxicological literature, and indoor air mean and 95% UCL concentrations with chronic health effect levels.

- Using the building-specific conceptual models, determine the public health implications of potential current and historical exposures to indoor air contamination that may have resulted from vapor intrusion into buildings on the base.
  - As described in *ATSDR Public Health Assessment Guidance Manual* [ATSDR 2005] and the technical supplement *Evaluating Vapor Intrusion Pathways* [ATSDR 2016], ATSDR staff will use both technical expertise and professional judgment to evaluate multiple lines of evidence in its assessment of the public health implications of the vapor intrusion pathway.
  - A table will provide the conclusions for each building the agency evaluates. This table will also summarize information such as building characteristics (e.g., use and mitigation system operation) and whether there are potential background (outdoor and/or indoor) air sources, air and/or biosparge systems, USTs, shallow groundwater plumes, and free product sources in the area.
    - The agency will not quantitatively distinguish contributions from different sources, but will use information in the database to qualitatively acknowledge those contributions in our building-specific conclusions.
  - For buildings with sufficient measured indoor air data, evaluate the combined exposure to multiple chemicals following the approach outlined in the ATSDR Guidance Manual for the Assessment of Joint Toxic Action of Chemical Mixtures [ATSDR 2004].
  - Evaluating more recent data, ATSDR will also determine effectiveness of vapor intrusion mitigation systems installed in buildings on the base.
    - If the agency's evaluation finds that indoor air contaminants in a building are below levels expected to harm health, the agency will conclude the system is effective at reducing indoor air contaminant concentrations for that building. Continued maintenance and monitoring is then usually recommended.

[27] ATSDR will complete the majority of the VI PHA before requesting the latest indoor air monitoring data for buildings with mitigation systems to ensure the agency is evaluating the most recent data for these buildings (i.e., 2014 indoor air data and forward).

- Provide any needed recommendations to protect health.

4. Limitations

The ATSDR VI evaluation process [ATSDR 2016] recommends the use of multiple lines of evidence to address the uncertainties inherent in the public health assessment of VI exposures. This VI PHA will rely on the availability of indoor air, soil gas, and groundwater data on a building-by-building basis, as well as other information about the buildings and areas, in order to develop defensible public health conclusions and recommendations. ATSDR notes that there are limitations in the available data specific to MCB Camp Lejeune, as well as limitations inherent to all VI evaluations. Some of these limitations are noted here:

- To create the VI database for use in the VI PHA, ATSDR 1) organized and categorized relevant documents, 2) used keyword searches to identify documents containing environmental sampling data, 3) identified indoor air, outdoor air, shallow groundwater, and soil gas data, 4) extracted data and entered the data into the database, and 5) completed data standardization. The agency acknowledges each of these steps has limitations. For example,
    - Although the file compression and optical character recognition methods in the "PDF Compressor" software ATSDR used to prepare documents for keyword searching typically worked as expected, neither procedure functioned perfectly.
    - ATSDR identified a limitation associated with the "shallow groundwater" search term. In some cases, documents that included shallow groundwater sampling data never included the actual words "shallow groundwater" and therefore were not identified by the search. However, no combination of search terms was identified that would find only those groundwater samples. As a result, ATSDR retained the "shallow" descriptor in the set of keywords, because searching for "shallow groundwater" identified the greatest portion of documents most relevant to vapor intrusion.
- ATSDR compiled available shallow groundwater estimates from the agency's and GA Tech's historical reconstruction modeling. The estimated chemical concentrations are simulated values with the uncertainty inherent in such simulations. The actual concentrations could have been higher or lower than the values generated by the historical reconstruction process. A detailed uncertainty analysis of the water modeling data using the Linear Control Model and the Latin Hypercube Sampling methodology is presented in the MCB Camp Lejeune Analyses and Historical Reconstruction document [Maslia et al. 2013]. See ATSDR's Camp Lejeune website for further information at https://www.atsdr.cdc.gov/sites/lejeune/index.html.
    - For the VI PHA, ATSDR plans to compare simulated shallow groundwater results for Model Layer 1 with measured shallow groundwater results for similar locations and time frames to determine whether the simulated concentrations are similar to the measured concentrations (most likely using a Kendall's Tau rank correlation coefficient, t-test, and/or Wilcoxon signed rank test.)
- ATSDR chose groundwater samples screened from a depth less than 15 ft bgs, as well as those screened between 15–≤25 ft when the water level within the well was within 15 ft of the ground

surface, to be representative of shallow groundwater. From its previous historical reconstruction modeling efforts, ATSDR mapped the groundwater using data that was available to the agency. Based on experience, expertise, and the geohydrology of the area, ATSDR made professional judgements where data were lacking. For example, data were only collected in areas of interest (i.e., contaminated areas); therefore, to get a generalized water-level map or tops of specific aquifers or horizons, ATSDR typically assumed the water table was a “subdued replica” of the topography and thus was about 5–10 ft bgs. CH2M reported the depth to groundwater ranges from 0 (surface water) to 22 ft below ground surface [CH2M Hill 2009]. Based on the previous ATSDR water-level mapping effort and CH2M reported depth to groundwater ranges, ATSDR choose groundwater samples screened from a depth ≤25 feet, when the water level within the well was within 15 ft of the ground surface, to be representative of shallow groundwater.

- ATSDR’s evaluations are limited by the available measured environmental data for each building. ATSDR’s VI database is composed of about 14,000 buildings. However, environmental sampling data are not available for all buildings. Based on very preliminary queries of the VI database, ATSDR believes at least 1,500 buildings have at least some measured environmental data inside the buildings and/or within 100 ft of the buildings. However, like most VI evaluations, whether indoor air, soil gas, and groundwater data are all available for each building will be a limiting factor.
- Although ATSDR will evaluate the measured environmental data (i.e., air, soil gas, and groundwater) in the agency’s VI database, the agency notes that much of the data were collected for purposes other than evaluating vapor intrusion. For example, older soil gas survey data were collected for the purpose of locating source areas or tracing groundwater plumes and may not have been collected in ways that are consistent with a vapor intrusion focused investigation. Further, some of the older historical data were collected and analyzed using procedures that have since been revised; therefore, some of the older sampling data might not be as accurate or precise as more recent results[28]. For example, older procedures for groundwater sample collection released VOCs to the air before the groundwater from the bailer was capped in a glass sample container.
- In its VI evaluation, ATSDR will attempt to use the VI database to distinguish between the contributions of VI contaminants and those of indoor and outdoor sources. The agency expects there to be limitations in the available data that will make this task difficult because 1) many of the buildings lack detailed information regarding building-specific uses (e.g., chemicals stored and/or processed within the building), 2) demolished buildings have uncertainty associated with past occupancy and exposure assumptions as well as building-specific uses, and 3) outdoor air data are only available for a few areas. Note, if ATSDR finds an indoor air concern not associated with vapor intrusion, the agency will inform MCB Camp Lejeune of the concern.

[28] Accuracy is about how close the measurement taken is to the actual (true) value while precision is the degree to which repeated measurements under unchanged conditions show the same results.

- Indoor air is a dynamic medium. Contaminant concentrations can change significantly over the course of a single day as a result of factors such as indoor air exchange rates or the introduction of a temporary source of contaminants (e.g., furniture polish or paint). ATSDR's evaluation cannot account for these daily variations.
- To evaluate temporal variability for chronic exposure concerns, ATSDR will need multiple samples collected over multiple seasons. Although about 50 buildings have had multiple indoor air measurements at several times and sample locations, at this time, ATSDR does not know whether these data will meet the agency's data requirements for an evaluation of seasonal variability. ATSDR will use Appendix B of its VI guidance [ATSDR 2016] and Holton [2013] as a guide to consider factors affecting temporal variability.
- Vapor intrusion can vary for many reasons. As the water table rises, it forces vapors through the soil. The water table fluctuates seasonally, during rain events, and in response to subsurface remediation efforts and water supply well pumping. Vapor intrusion can be influenced by underground utilities (i.e., potential pathways) which are widespread at the base. In addition, several of the buildings on the base are multi-purpose with a combination of office and storage spaces, variable ceiling heights, and heating/cooling systems, leading to a highly variable potential for vapor intrusion. To complete its building-specific analyses in a timely manner, ATSDR will likely not be able to go into in-depth detail regarding these factors except when the information is readily available.
- Because of the magnitude of the site (i.e., thousands of buildings), an important step is focusing on those building where ATSDR's public health recommendations will have the greatest impact at protecting public health (i.e., mitigating ongoing exposures of concern). Therefore, the VI PHA will not evaluate all buildings at the same level of specificity.
- ATSDR usually reviews floor plans and spatial distributions of contaminants under the building (i.e., subslab gas under the building's floor). Given the magnitude of the site (i.e., thousands of buildings), the agency will complete floor plan and subslab gas evaluations as data availability and resources allow for those buildings with the highest VI potential. During the evaluation, ATSDR will conduct exploratory data analysis to look at other ways to analyze the data, such as reviewing the spatial distribution of groundwater samples and visually interpolating concentrations under the building where no subslab gas measurements exist.
- Calculating historical indoor air estimates will introduce a large degree of uncertainty. ATSDR plans to explore ways to describe the level of uncertainty in its analysis, but at this time, cannot be specific on what approaches might be appropriate. Although the agency is anticipating that some buildings will have available measured indoor air data for comparison to the estimated concentrations (e.g., determine the relationship between the estimated and measured concentrations), this may not be the case.
- Implementation of this Work Plan will likely result in some revisions to the procedures. Any major modifications to the Work Plan during its implementation will be documented in the VI PHA.

5. Presentation and Documentation of Results

ATSDR will publish the results of the Camp Lejeune vapor intrusion evaluation in a PHA. The PHA will contain the agency's conclusions, recommendations, and a plan for activities to protect public health. The PHA will receive several layers of review before being made available to the public for comment. During the comment period, the public will have an opportunity to review the PHA and provide additional information and comments. After reviewing the comments and making necessary revisions, ATSDR will release a final PHA. Steps in preparing the VI PHA include the following:

- Develop this draft Work Plan describing the process to develop the VI PHA.
- Release this draft Work Plan for review by the Community Assistance Panel (CAP), MCB Camp Lejeune and its contractors, and external peer reviewers.
- Incorporate appropriate changes into the draft Work Plan, and then share a final Work Plan with the CAP, MCB Camp Lejeune and its contractors, and external peer reviewers.
- Develop a draft VI PHA that will receive internal agency review.
- Release the draft VI PHA for review by the CAP, Camp Lejeune and its contractors, and external peer reviewers.
- Incorporate appropriate changes into the draft VI PHA, and then release the draft VI PHA for comment by the public.
- Incorporate appropriate changes into the draft VI PHA, and then release a final VI PHA that includes both the public comments and ATSDR's responses indicating how each comment was addressed.

6. Proposed Timeline

To date, ATSDR has identified and organized approximately 23,000 historical documents and reports containing data of interest for the VI PHA. MCB Camp Lejeune soil vapor intrusion data entry process was completed on September 22, 2016 with a total of 1,628,900 rows of data extracted from 2,107 documents. Also, manual geo-referencing of data without a location was completed for 29,528 data points and data standardization was completed for all 60 fields of data. Work on the VI PHA will continue to progress in line with the timeline in Table 1.

Table 1. Timeline for ATSDR's Vapor Intrusion Public Health Assessment (2 pages)

Activity	Start	Finish
Organize and categorize relevant documents from Department of Navy, U.S. Environmental Protection Agency, and North Carolina Department of Environment and Natural Resources	01/02/2013	Completed
Identify indoor air, shallow groundwater, and soil gas data; extract data and enter the data into a database; and complete data standardization	03/01/2015	Completed
Develop a pre-draft work plan	04/15/2017	Completed
Submit pre-draft work plan for site-team and branch review	9/20/2017	Completed
Update pre-draft work plan per comments	9/26/2017	Completed
Submit pre-draft work plan for ATSDR clearance	10/10/2017	Completed

Activity	Start	Finish
Update pre-draft work plan per comments	10/27/2017	Completed
Release pre-draft work plan to reviewers for comment (CAP and MCB Camp Lejeune)	12/04/2017	Completed
Update pre-draft work plan per comments	12/18/2017	Completed
Release draft work plan to external peer reviewers for comment	01/31/2018	Completed
Update and finalize draft work plan per comments; clear through Division; share final work plan with reviewers (external peer, CAP, MCB Camp Lejeune)	03/15/2018	Completed
Develop a pre-draft VI PHA	10/06/2017	12/30/2018
Submit draft VI PHA for ATSDR clearance	12/30/2018	04/15/2019
Release draft VI PHA to reviewers for comment (external peer, CAP, MCB Camp Lejeune)	04/16/2019	06/01/2019
Update draft VI PHA per comments	06/02/2019	12/01/2019
Release draft VI PHA for public comment	12/02/2019	02/02/2020
Update draft VI PHA per comments	02/03/2020	04/30/2020
Submit draft VI PHA for ATSDR clearance	04/31/2020	07/15/2020
Release final VI PHA	07/15/2020	--

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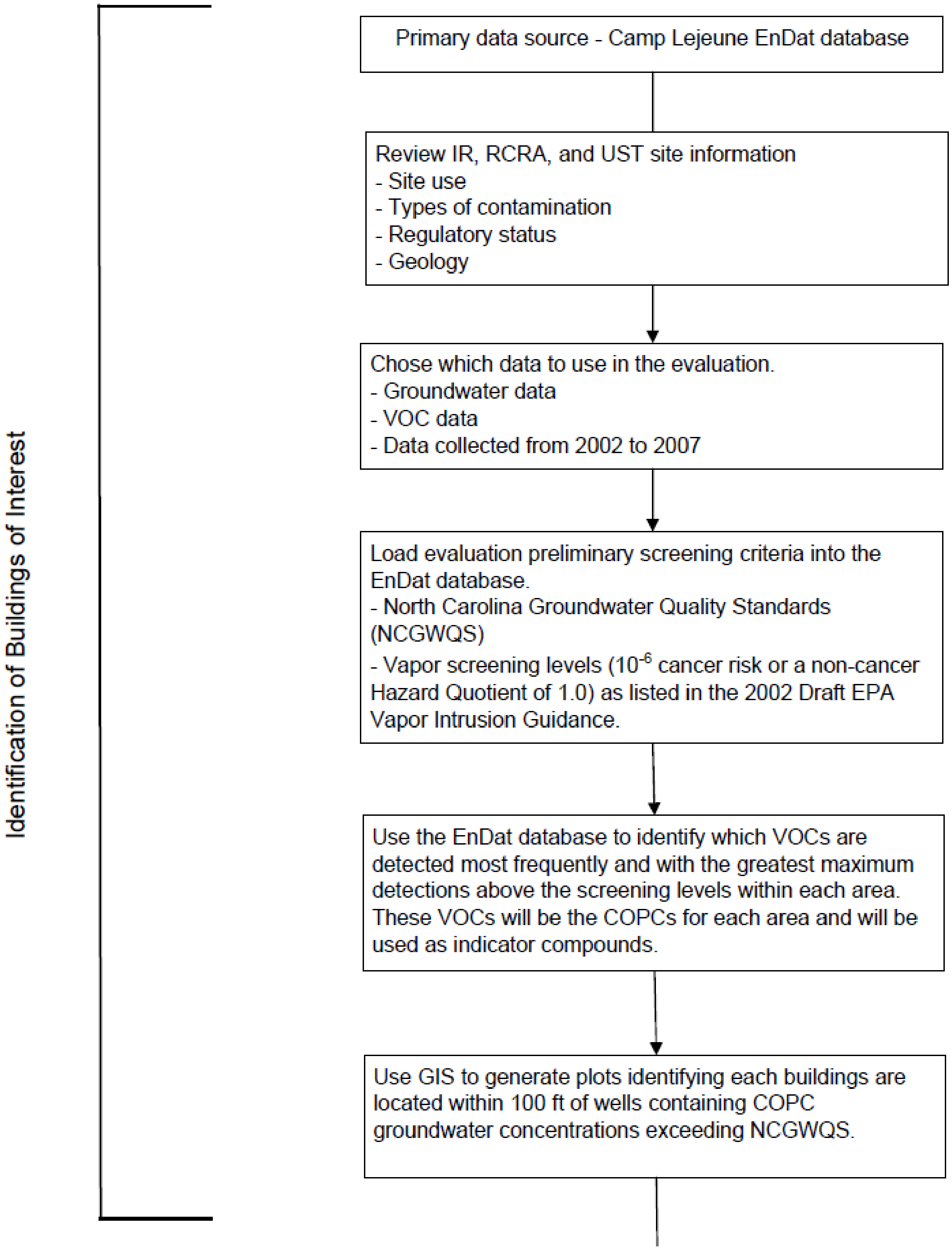
Appendix A. Figures

Figure 1A. CH2M's Vapor Intrusion Evaluation Approach* (page 1 of 3)

[Source: adapted from CH2M 2009]



* This figure shows the procedure CH2M followed when conducting its vapor intrusion investigation, which is different than ATSDR's approach (see Section 2.3 of the main text).

Figure 1A. CH2M's Vapor Intrusion Evaluation Approach (page 2 of 3)

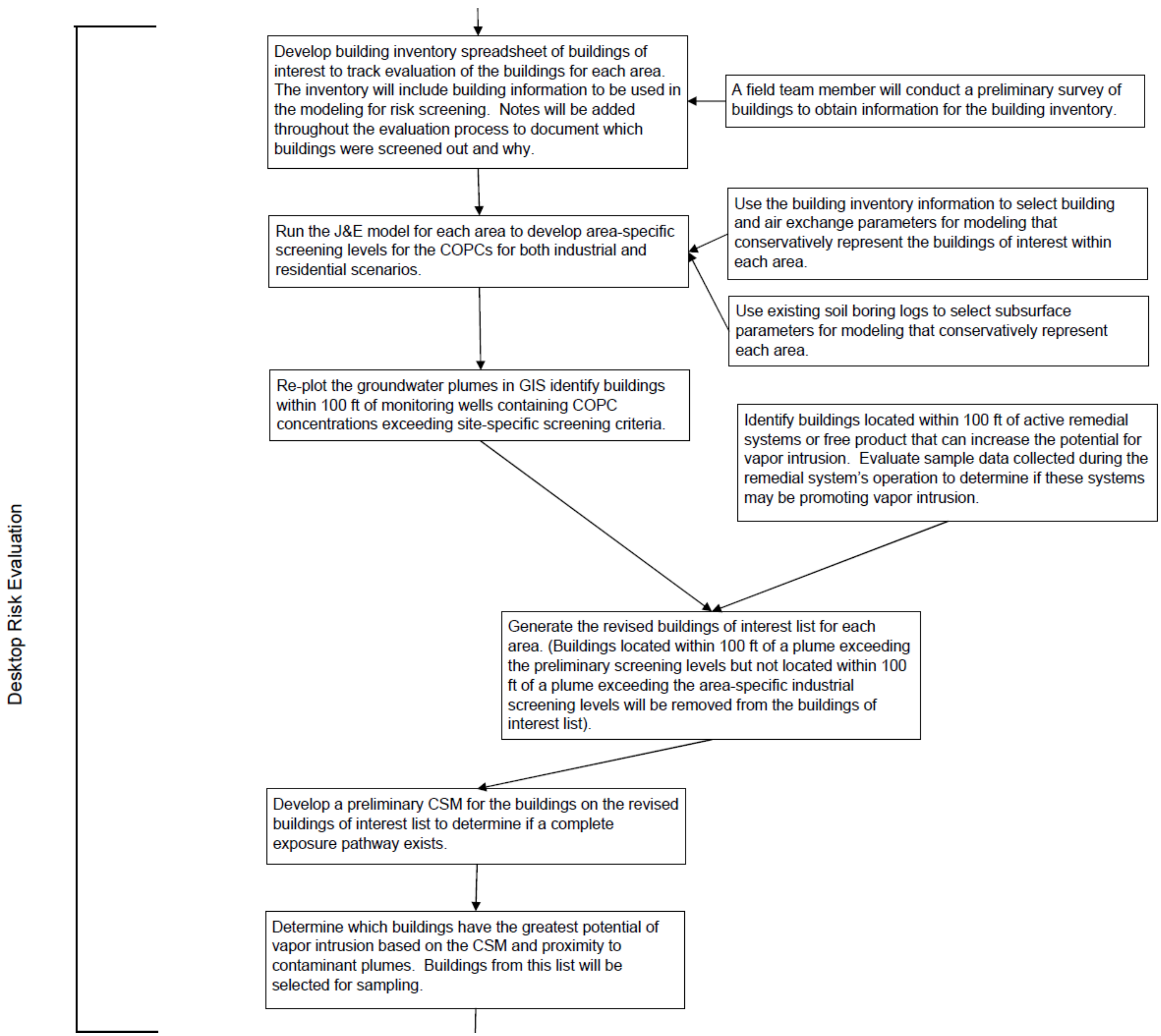


Figure 1A. CH2M's Vapor Intrusion Evaluation Approach (page 3 of 3)

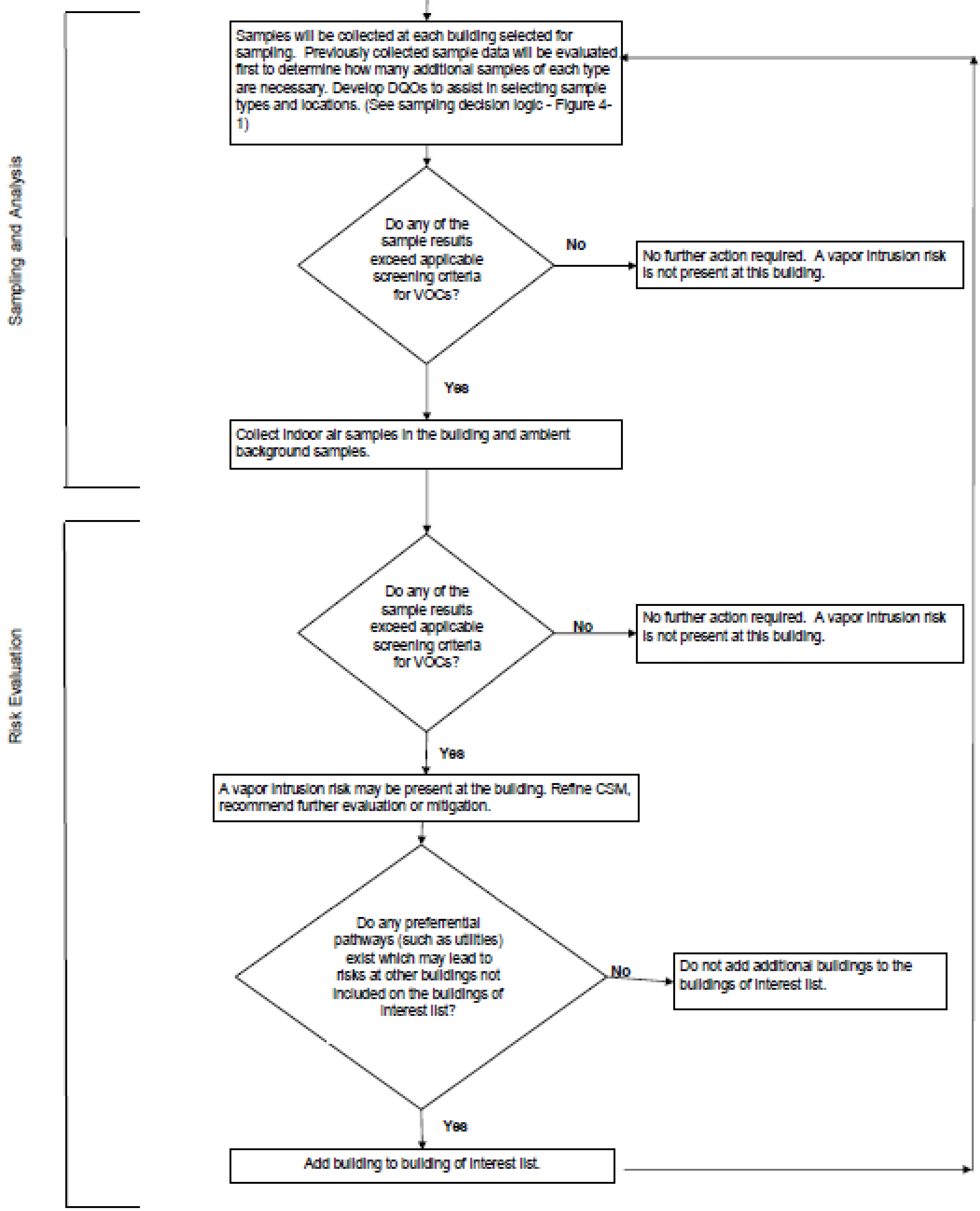
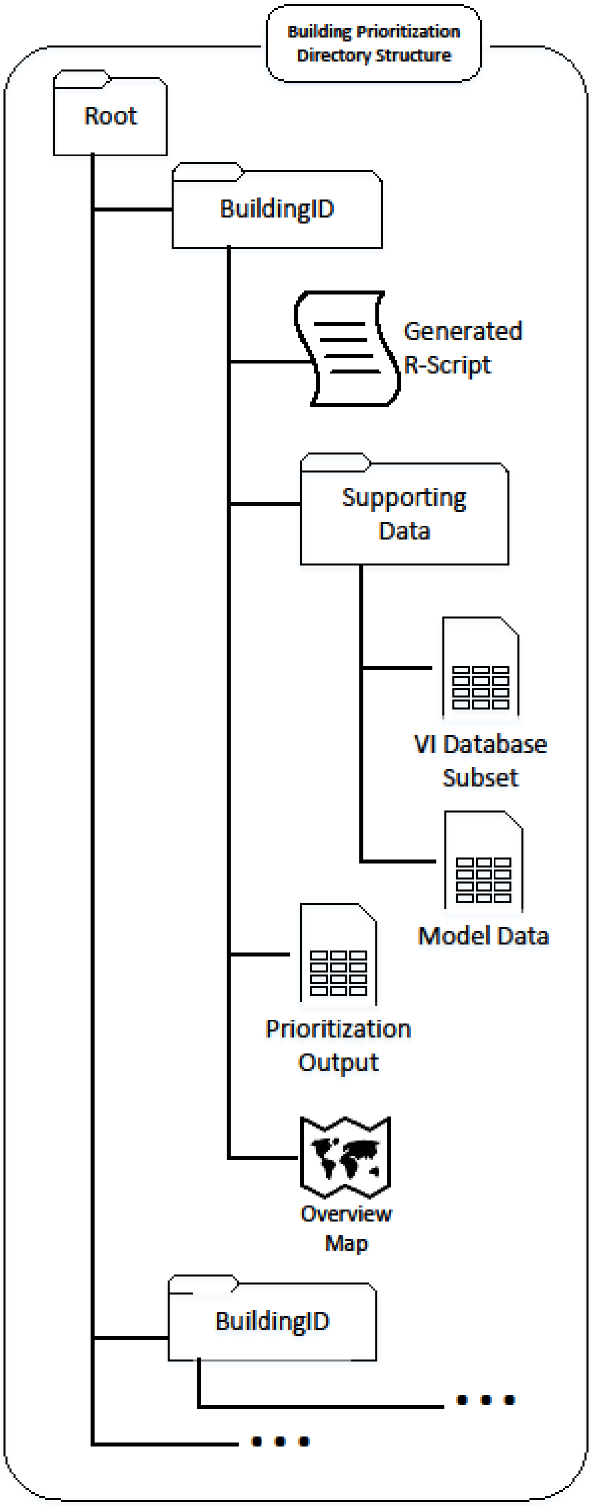


Figure 2A. ATSDR's Prioritization Scheme Directory Structure



Root is the top-level directory. It will have a subdirectory for each building that has any samples within 100 feet. It may also contain supporting documentation not shown in this diagram, such as a copy of the work plan, global code, copy of guidance documents, map documents, etc.

The R-Script will be responsible for populating Timeframe and Media Factor Analysis Charts. It will also complete the Results Output Chart.

Vapor Intrusion (VI) database subset will be a full join of all of the results within 100 feet of the respective building. It will include distance field to simplify changes to the sample-building proximity parameter.

Model Data will be the simulated samples, standardized to a single format designed to mirror the VI Database Subset fields that are needed for the R-Script calculations.

Prioritization Output will be a single Excel file with multiple tabs, each representing an analysis chart output as specified in the Camp Lejeune Work Plan.

Overview Map will be a generated map (possibly a pdf) that will show the respective building and any relevant supporting data.

Figure 3A. ATSDR's Prioritization Scheme High Level Data Flow

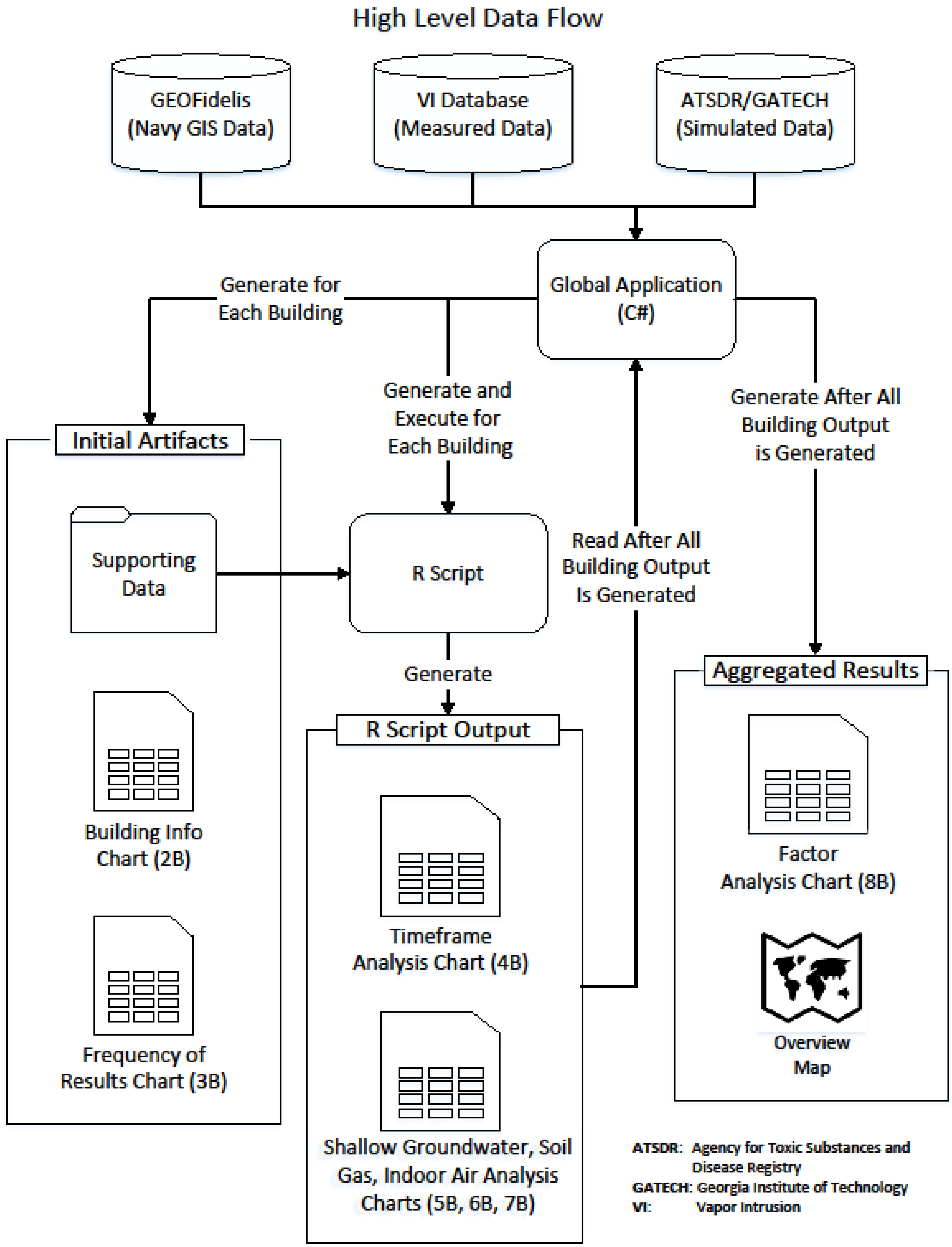
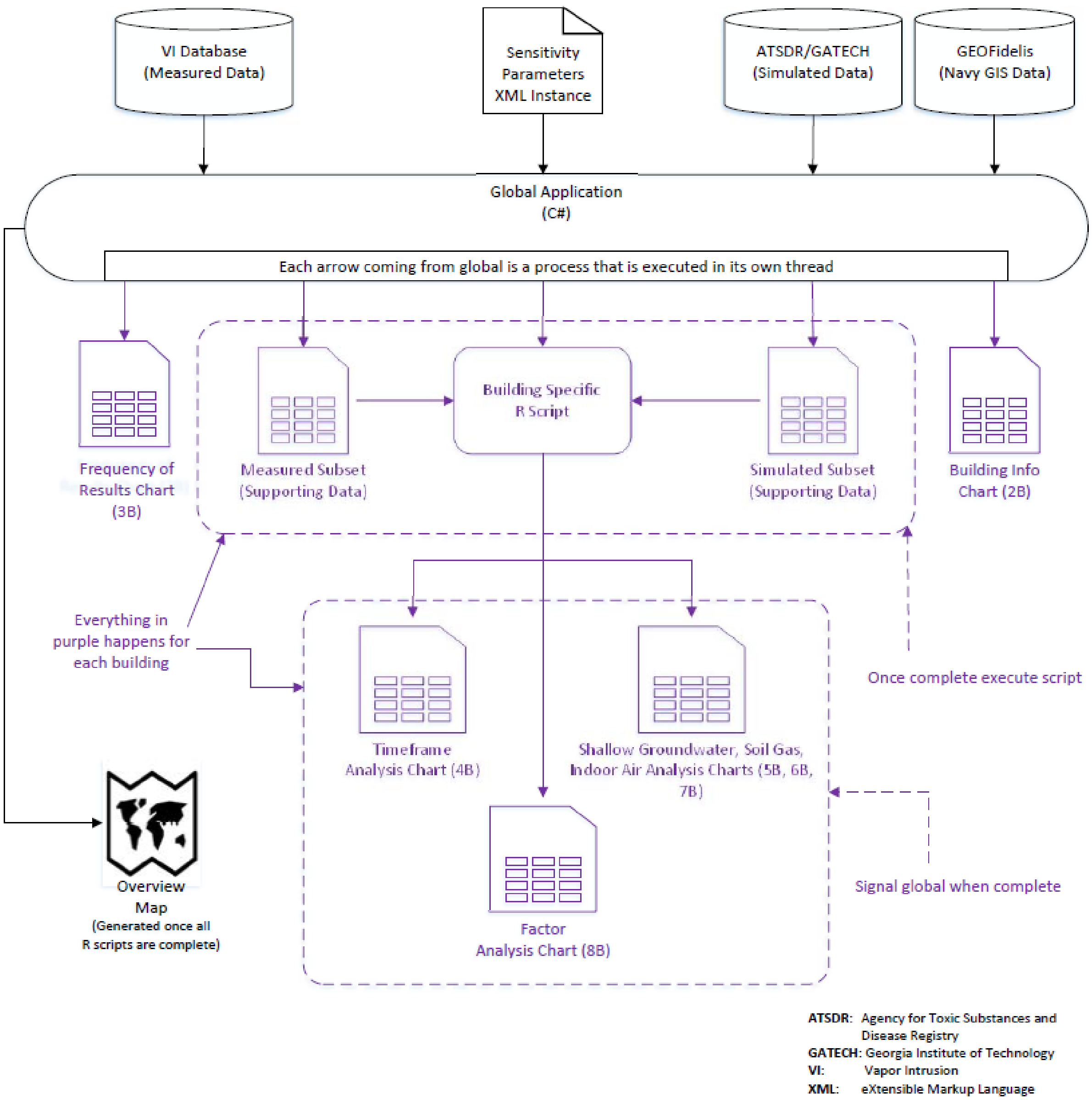


Figure 4A. ATSDR's Prioritization Scheme Concurrency Diagram



Appendix B. Tables

Table 1B. Chemicals for Vapor Intrusion Assessment (2 pages)

CAS #	Chemical Name	CAS #	Chemical Name
83-32-9	Acenaphthene (SVOC)	120-61-6	Dimethylterephthalate
75-07-0	Acetaldehyde	513-37-1	Dimethylvinylchloride
67-64-1	Acetone (VOC)	505-29-3	Dithiane, 1,4-
75-86-5	Acetone cyanohydrin	106-89-8	Epichlorohydrin
75-05-8	Acetonitrile	106-88-7	Epoxybutane, 1,2-
98-86-2	Acetophenone	759-94-4	EPTC
107-02-8	Acrolein	141-78-6	Ethyl acetate
107-13-1	Acrylonitrile	140-88-5	Ethyl acrylate
107-05-1	Allyl chloride	75-00-3	Ethyl chloride
120-12-7	Anthracene (SVOC)	60-29-7	Ethyl ether
11104-28-2	Aroclor 1221	97-63-2	Ethyl methacrylate
11141-16-5	Aroclor 1232	100-41-4	Ethylbenzene (VOC)
103-33-3	Azobenzene	75-21-8	Ethylene oxide
100-52-7	Benzaldehyde	151-56-4	Ethyleneimine
71-43-2	Benzene (VOC)	86-73-7	Fluorene (SVOC)
108-98-5	Benzenethiol	110-00-9	Furan
98-07-7	Benzotrichloride	822-06-0	Hexamethylene diisocyanate, 1,6-
100-44-7	Benzyl chloride	110-54-3	Hexane, N-
92-52-4	Biphenyl, 1,1'-	591-78-6	Hexanone, 2- (VOC)
108-60-1	Bis(2-chloro-1-methylethyl) ether	74-90-8	Hydrogen cyanide
111-44-4	Bis(2-chloroethyl)ether (SVOC)	NA (JP-7)	JP-7
542-88-1	Bis(chloromethyl)ether	7439-97-6	Mercury (elemental)
107-04-0	Bromo-2-chloroethane, 1-	126-98-7	Methacrylonitrile
108-86-1	Bromobenzene (VOC)	79-20-9	Methyl acetate
74-97-5	Bromochloromethane (VOC)	96-33-3	Methyl acrylate
75-27-4	Bromodichloromethane (VOC)	78-93-3	Methyl ethyl ketone (2-butanone) (VOC)
74-83-9	Bromomethane (VOC)	108-10-1	Methyl isobutyl ketone (4-methyl-2-pentanone) (VOC)
106-99-0	Butadiene, 1,3-		
104-51-8	Butylbenzene, n- (VOC)	624-83-9	Methyl isocyanate
135-98-8	Butylbenzene, sec-	80-62-6	Methyl methacrylate
98-06-6	Butylbenzene, tert-	25013-15-4	Methyl styrene (mixed isomers)
75-15-0	Carbon disulfide (VOC)	1634-04-4	Methyl tert-butyl ether (MTBE) (VOC)
56-23-5	Carbon tetrachloride (VOC)	75-09-2	Methylene chloride (VOC)
75-68-3	Chloro-1,1-difluoroethane, 1-	90-12-0	Methylnaphthalene, 1-
126-99-8	Chloro-1,3-butadiene, 2-	91-57-6	Methylnaphthalene, 2- (SVOC)
107-20-0	Chloroacetaldehyde, 2-	98-83-9	Methylstyrene, Alpha-
108-90-7	Chlorobenzene (VOC)	8012-95-1	Mineral oils
98-56-6	Chlorobenzotrifluoride, 4-	64724-95-6	Naphtha, high flash aromatic (HFAN)
109-69-3	Chlorobutane, 1-	91-20-3	Naphthalene (SVOC)
75-45-6	Chlorodifluoromethane	98-95-3	Nitrobenzene (SVOC)
67-66-3	Chloroform (VOC)	75-52-5	Nitromethane
74-87-3	Chloromethane (VOC) 107-	79-46-9	Nitropropane, 2-
30-2	Chloromethyl methyl ether	924-16-3	Nitroso-di-N-butylamine, N-
91-58-7	Chloronaphthalene, Beta- (SVOC)	88-72-2	Nitrotoluene, o-
95-57-8	Chlorophenol, 2- (SVOC)	111-84-2	Nonane, n-
76-06-2	Chloropicrin	109-66-0	Pentane, n-
95-49-8	Chlorotoluene, o- (VOC)	75-44-5	Phosgene
106-43-4	Chlorotoluene, p- (VOC)	123-38-6	Propionaldehyde
123-73-9	Crotonaldehyde, trans-	103-65-1	Propyl benzene (VOC)
98-82-8	Cumene	115-07-1	Propylene

57-12-5	Cyanide (CN-)
460-19-5	Cyanogen
506-68-3	Cyanogen bromide
506-77-4	Cyanogen chloride
110-82-7	Cyclohexane
132-64-9	Dibenzofuran (SVOC)
96-12-8	Dibromo-3-chloropropane, 1,2- (VOC)
124-48-1	Dibromochloromethane (VOC)
106-93-4	Dibromoethane, 1,2-
74-95-3	Dibromomethane (methylene bromide) (VOC)
764-41-0	Dichloro-2-butene, 1,4-
1476-11-5	Dichloro-2-butene, cis-1,4-
110-57-6	Dichloro-2-butene, trans-1,4-
95-50-1	Dichlorobenzene, 1,2- (SVOC)
106-46-7	Dichlorobenzene, 1,4- (SVOC)
75-71-8	Dichlorodifluoromethane (VOC)
75-34-3	Dichloroethane, 1,1- (VOC)
107-06-2	Dichloroethane, 1,2- (VOC)
75-35-4	Dichloroethylene, 1,1- (VOC)
540-59-0	Dichloroethylene, 1,2- (mixed isomers) (VOC)
156-59-2	Dichloroethylene, 1,2-cis- (VOC)
156-60-5	Dichloroethylene, 1,2-trans- (VOC)
78-87-5	Dichloropropane, 1,2- (VOC)
142-28-9	Dichloropropane, 1,3- (VOC)
542-75-6	Dichloropropene, 1,3- (VOC)
77-73-6	Dicyclopentadiene
75-37-6	Difluoroethane, 1,1-
94-58-6	Dihydrosafrole
108-20-3	Diisopropyl ether
1445-75-6	Diisopropyl methylphosphonate
121-69-7	Dimethylaniline, N,N-
75-56-9	Propylene oxide
129-00-0	Pyrene (SVOC)
110-86-1	Pyridine
100-42-5	Styrene (VOC)
630-20-6	Tetrachloroethane, 1,1,1,2- (VOC)
79-34-5	Tetrachloroethane, 1,1,2,2- (VOC)
127-18-4	Tetrachloroethylene (VOC)
811-97-2	Tetrafluoroethane, 1,1,1,2-
109-99-9	Tetrahydrofuran
463-56-9	Thiocyanate
108-88-3	Toluene (VOC)
76-13-1	Trichloro-1,2,2-trifluoroethane, 1,1,2-
87-61-6	Trichlorobenzene, 1,2,3-
120-82-1	Trichlorobenzene, 1,2,4- (SVOC)
71-55-6	Trichloroethane, 1,1,1- (VOC)
79-00-5	Trichloroethane, 1,1,2- (VOC)
79-01-6	Trichloroethylene (VOC)
75-69-4	Trichlorofluoromethane (VOC)
598-77-6	Trichloropropane, 1,1,2-
96-18-4	Trichloropropane, 1,2,3- (VOC)
96-19-5	Trichloropropene, 1,2,3-
121-44-8	Triethylamine
526-73-8	Trimethylbenzene, 1,2,3- (VOC)
95-63-6	Trimethylbenzene, 1,2,4- (VOC)
108-67-8	Trimethylbenzene, 1,3,5- (VOC)
108-05-4	Vinyl acetate (VOC)
593-60-2	Vinyl bromide
75-01-4	Vinyl chloride (VOC)
108-38-3	Xylene, m- (VOC)
95-47-6	Xylene, o- (VOC)
106-42-3	Xylene, p- (VOC)
1330-20-7	Xylenes (VOC)

Source: ATSDR 2016.

SVOC semi-volatile organic compound
VOC volatile organic compound

Table 2B. Building Information Factor Analysis Chart

Factor*	Building Information								
	Key	**Condition**	**Scale†**	**Key**	**Condition**	**Scale†**	**Key**	**Condition**	**Scale†**
1. Type of structure	**Building**	Structure is/was a building (i.e., enclosed structure with a roof and walls)	**H**	**≠ Building**	There are implications structure is/was not a building	**L**	**Unknown**	It is unknown if the structure is/was a building	**?**
2. Use	**School, Residence, Health care, Workplace, Warehouse, or Storage**	Building is/was used as a school, residence, health care, workplace, warehouse, or storage	**H**	**Short-duration use**	There are implications building is/was unlikely to remain occupied by the same person (e.g., latrine)	**L**	**Unknown**	Building use is/was not known	**?**
3. Status	**Current**	Building currently exists	**H**	**Past**	Building was demolished	**M**	**Unknown**	Building status is not known	**?**
4. Size	**≤ 5000 ft^2**	Building is/was ≤ 5000 ft^2	**H**	**> 5000 ft^2**	Building is/was > 5000 ft^2	**M**	--	--	--

ft feet
-- not applicable

* For each factor, pick the "condition" that is met by the building and mark the associated "key" word in Table 8B, Appendix B, for that building under the appropriate column. Complete Table 2B for all buildings.

† Scale codes relate to the concern level ATSDR places on the condition, which are: H = "high," M = "medium," L = "low," and ? = "unknown"

Table 3B. Frequency of Results Factor Analysis Chart

Factor*	Points		
	2	**1**	**0**
1. Groundwater	≥ 8 shallow groundwater samples[†] were collected under/within 100 ft of the building, ≥ 4 of those samples have detected results, and ≥ 20% of the samples have detected results during any time period[‡]	Shallow groundwater samples with at least one detected result were collected under/within 100 ft of the building during any time period	Shallow groundwater samples were either not collected or there were no shallow groundwater samples with detected results within 100 ft of the building
2. Soil gas	≥ 8 soil gas samples were collected within 100 ft of the building, ≥ 4 of those samples have detected results, and ≥ 20% of the samples have detected results during any time period	Soil gas samples with at least one detected result were collected within 100 ft of the building during any time period	Soil gas samples were either not collected or there were no soil gas samples with detected results within 100 ft of the building
3. Indoor air	≥ 8 indoor air samples were collected in the building, ≥ 4 of those samples have detected results, and ≥ 20% of the samples have detected results during any time period	Indoor air samples with at least one detected result were collected in the building during any time period	Indoor air samples were either not collected or there were no indoor air samples with detected results in the building

ft feet

* For the measured results, complete this chart for all contaminants listed in Table 1B, Appendix B, on a building-by-building basis. For each contaminant, add the points collected for this chart to Table 8B, Appendix B, for each specific building under the "Frequency of Results" column.

† ATSDR's exposure point concentration workgroup simulated confidence limits coverage for more typical distributional assumptions and recommended a minimum of 8 samples, with at least 4 of those samples having detected results and at least 20% of the samples having detected results, as the floor for sample size to have a reasonable frequency of the upper confidence level (UCL) being within 10% of the true population mean. The agency expects guidance for estimating exposure point concentrations, which includes these recommendations for minimum sample size, to be released soon.

‡ The four time periods of measured data are the 1980s, 1990s, 2000–2007, and 2008–2013.

Table 4B. Timeframe Factor Analysis Chart

Factor*	Points			
	1	**0.75**	**0.5**	**0**
1. Average groundwater concentration[†]: simulated data	Highest average contaminant concentration in a location under or within 100 ft of the building occurred in the 2000s	Highest average contaminant concentration in a location under or within 100 ft of building occurred in the 1990s	Highest average contaminant concentration in a location under or within 100 ft of the building occurred in the 1980s	There are no simulated shallow groundwater data with concentrations greater than 0 ppb in locations under or within 100 ft of the building
2. 95% UCL[‡] shallow groundwater concentration: measured data	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 2000s	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 1990s	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 1980s	There are either no shallow groundwater data or no shallow groundwater samples with detected results within 100 ft of the building
3. 95% UCL soil gas concentration: measured data	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 2000s	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 1990s	Highest 95% UCL contaminant concentration within 100 ft of the building occurred in the 1980s	There are either no soil gas data or no soil gas samples with detected results within 100 ft of the building
4. 95% UCL indoor air concentration: measured data	Highest 95% UCL contaminant concentration in the building occurred in the 2000s	Highest 95% UCL contaminant concentration in the building occurred in the 1990s	Highest 95% UCL contaminant concentration in the building occurred in the 1980s	There are either no indoor air data or no indoor air samples with detected results for the building

ft feet
ppb parts per billion
UCL upper confidence level of the mean

* Complete this chart for all contaminants listed in Table 1B, Appendix B, on a building-by-building basis using both measured and simulated data. For each contaminant, add the points collected for the chart to Table 8B, Appendix B, for each specific building under the “Timeframe” column.

† For those instances where ATSDR was not able to calculate an average for the simulated results, the contaminant’s maximum value will be used in place of the average value.

‡ For those instances where ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant’s maximum value will be used in place of the 95% UCL value.

Table 5B. Shallow Groundwater Factor Analysis Chart (2 pages)

Factor*	Points			
	2	**1**	**0**	**-1**
1. Initial screening: simulated data under or within 100 ft of the building	Maximum contaminant concentration exceeds its short-term VICV and highest average[†] contaminant concentration exceeds its long-term VICV	Maximum contaminant concentration exceeds its short-term or highest average contaminant concentration exceeds long-term VICVs	There are no simulated data	Contaminant concentrations do not exceed VICVs
2. Initial screening: measured data within 100 ft of the building	Maximum contaminant concentration exceeds its short-term VICV and highest 95% UCL[‡] contaminant concentration exceeds its long-term VICV during any time period[¶]	Maximum contaminant concentration exceeds its short-term VICV or highest 95% UCL contaminant concentration exceeds its long-term VICV during any time period	There are either no shallow groundwater data or no shallow groundwater samples with detected results	Maximum contaminant concentration does not exceed its short-term VICV and highest 95% UCL contaminant concentration does not exceed its long-term VICV during any time period
3. Magnitude of exceedance: simulated data under or within 100 ft of the building	Maximum contaminant and/or highest average contaminant concentration exceeds 100x its respective VICV	Maximum contaminant and/or highest average contaminant concentration exceeds 10x its respective VICV	Choose for all other situations	--
4. Magnitude of exceedance: measured data within 100 ft of the building	Maximum contaminant and/or highest 95% UCL contaminant concentration exceeds 100x its respective VICV during any time period	Maximum contaminant and/or highest 95% UCL contaminant concentration exceeds 10x its respective VICV during any time period	Choose for all other situations	--
5. Coefficient of variation: measured data within 100 ft of the building	Contaminant has a coefficient of variation ≥ 200% during any time period	Contaminant has a coefficient of variation ≥ 100% during any time period	Choose for all other situations	--
6. Percent detected: measured data within 100 ft of the building	--	Contaminant was detected ≥ 20% of the time during any time period	Choose for all other situations	--

ft feet
UCL upper confidence level of the mean
VICV vapor intrusion comparison value

-- not applicable

* Complete this chart for all contaminants listed in Table 1B, Appendix B, on a building-by-building basis using both measured and simulated data. For each contaminant, add the points collected for the chart to Table 8B, Appendix B, for each specific building under the "Shallow Groundwater" column.

† For those instances where ATSDR was not able to calculate an average for the simulated results, the contaminant's maximum value will be used in place of the average value.

‡ For those instances where ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant's maximum value will be used in place of the 95% UCL value.

¶ The four time periods of measured data are the 1980s, 1990s, 2000–2007, and 2008–2013.

Table 6B. Soil Gas Factor Analysis Chart

Factor*	Points			
	2	**1**	**0**	**-1**
1. Initial screening: measured data within 100 ft of the building	Maximum contaminant concentration exceeds its short-term VICV <u>and</u> highest 95% UCL[†] contaminant concentration exceeds its long-term VICV during any time period[‡]	Maximum contaminant concentration exceeds its short-term VICV <u>or</u> highest 95% UCL contaminant concentration exceeds its long-term VICV during any time period	There are either no soil gas data or no soil gas samples with detected results	Maximum contaminant concentration does exceed its short-term VICV <u>and</u> highest 95% UCL contaminant concentration does not exceed its long-term VICV during any time period
2. Magnitude of exceedance: measured data within 100 ft of the building	Maximum contaminant and/or highest 95% UCL contaminant concentration exceeds 100x its respective VICV during any time period	Maximum contaminant and/or highest 95% UCL contaminant concentration exceeds 10x its respective VICV during any time period	Choose for all other situations	--
3. Coefficient of variation: measured data within 100 ft of the building	Contaminant has a coefficient of variation ≥ 200% during any time period	Contaminant has a coefficient of variation ≥ 100% during any time period	Choose for all other situations	--
4. Percent detected: measured data within 100 ft of the building	--	Contaminant was detected ≥ 20% of the time during any time period	Choose for all other situations	--

ft feet
UCL upper confidence level of the mean
VICV vapor intrusion comparison value
-- not applicable

* Complete this chart for all contaminants listed in Table 1B, Appendix B, on a building-by-building basis using both measured and simulated data. For each contaminant, add the points collected for the chart to Table 8B, Appendix B, for each specific building under the "Soil Gas" column.

† For those instances where ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant's maximum value will be used in place of the 95% UCL value.

‡ The four time periods of measured data are the 1980s, 1990s, 2000–2007, and 2008–2013.

Table 7B. Indoor Air Factor Analysis Chart

Factor*	Points			
	2	1	0	-1
1. Initial screening: measured data within the building	Maximum contaminant concentration† exceeds its short-term CV and 95% UCL‡ contaminant concentration exceeds its long-term CV during any time period¶	Maximum contaminant concentration exceeds its short-term CV or 95% UCL contaminant concentration exceeds its long-term CV during any time period	There are either no indoor air data or no indoor air samples with detected results	Maximum contaminant concentration does not exceed its short-term CV and 95% UCL contaminant concentration does not exceed its long-term CV during any time period
2. Magnitude of exceedance: measured data within the building	Maximum contaminant and/or 95% UCL contaminant concentration exceeds 100x its respective VICV during any time period	Maximum and/or 95% UCL contaminant concentration exceeds 10x its respective VICV during any time period	Choose for all other situations	--
3. Coefficient of variation: measured data within the building †	Contaminant has a coefficient of variation ≥ 200% during any time period	Contaminant has a coefficient of variation ≥ 100% during any time period	Choose for all other situations	--
4. Percent detected: measured data within the building	--	Contaminant was detected ≥ 20% of the time during any time period	Choose for all other situations	--

CV comparison value
ft feet
UCL upper confidence level of the mean
-- not applicable

* For the measured results, complete this chart for all contaminants listed in Table 1B, Appendix B, on a building-by-building basis. For each contaminant, add the points collected for the chart to Table 8B, Appendix B, for each specific building under the “Indoor Air” column.

† For workplace buildings, “adjusted-measurements” for indoor air will be used to represent maximum concentrations and used during calculations (see Section 3.1.5, main bullet 1, sub-bullet 2 of the main text).

‡ For those instances where ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant’s maximum value will be used in place of the 95% UCL value.

¶ The four time periods of measured data are the 1980s, 1990s, 2000–2007, and 2008–2013.

Table 8B. Factor Analysis Chart Results

Building*	Type of Structure	Use	Status	Size	Total Factor Analysis Results†	Conclusion VI Risk‡
	[Table 2B]¶	[Table 2B]	[Table 2B]	[Table 2B]		

Contaminant§	Factor Analysis Results								
	Frequency of Results	Timeframe	Shallow Groundwater	Shallow Groundwater Value Type**	Soil Gas	Soil Gas Value Type††	Indoor Air	Indoor Air Value Type‡‡	Overall Points¶¶
	[Table 3B]	[Table 4B]	[Table 5B]		[Table 6B]		[Table 7B]		

VI vapor intrusion

* On a building-by-building basis, complete this entire chart.
† To determine the "Total Factor Analysis Results," sum the results found in the "Overall Points" column of this chart.
‡ Based on the information in the chart, designate the building's VI risk as "high potential," "medium potential," "low potential," "no apparent," or "unknown".
¶ The table number found inside the brackets of individual cells in this chart indicates where the cell information can be obtained.
§ On a contaminant-by-contaminant basis for each building, complete the "Factor Analysis Results" row.
** If the contaminant's maximum value was used in place of the 95% UCL value for points collected in Table 5B, record "Max" for the cell; if the 95% UCL value was used, mark "95UCL" in this cell.
†† If the contaminant's maximum value was used in place of the 95% UCL value for points collected in Table 6B, record "Max" for the cell; if the 95% UCL value was used, mark "95UCL" in this cell.
‡‡ If the contaminant's maximum value was used in place of the 95% UCL value for points collected in Table 7B, record "Max" for the cell; if the 95% UCL value was used, mark "95UCL" in this cell.
¶¶ To determine the overall points for each contaminant in each row, sum the results for each factor with a numerical value.

Table 9B. Air Comparison Values (6 pages)

CAS #	Chemical Name*	Long-Term Air CV† (ppb)	Long-Term CV Source‡	Short-Term Air CV¶ (ppb)	Short-Term CV Source‡
000075-07-0	Acetaldehyde	0.25	D		
000067-64-1	Acetone (VOC)	13,000	C	13,000	B
000075-86-5	Acetone cyanohydrin	0.60	F		
000075-05-8	Acetonitrile	36	E		
000107-02-8	Acrolein	0.0087	E	0.040	B
000107-13-1	Acrylonitrile	0.0068	D	100	A
000107-05-1	Allyl chloride	0.32	E		
011104-28-2	Aroclor 1221	0.00064	G		
011141-16-5	Aroclor 1232	0.00064	G		
000103-33-3	Azobenzene	0.0043	D		
000071-43-2	Benzene (VOC)	0.040	D	6.0	B
000100-44-7	Benzyl chloride	0.011	G		
000092-52-4	Biphenyl, 1,1'-	0.067	F		
000111-44-4	Bis(2-chloroethyl)ether (SVOC)	0.00052	D	20	B
000542-88-1	Bis(chloromethyl)ether	0.0000034	D	0.30	B
000107-04-0	Bromo-2-chloroethane, 1-	0.00080	G		
000108-86-1	Bromobenzene (VOC)	9.3	E		
000074-97-5	Bromochloromethane (VOC)	7.9	F		
000075-27-4	Bromodichloromethane (VOC)	0.011	G		
000074-83-9	Bromomethane (VOC)	1.3	E	50	B
000106-99-0	Butadiene, 1,3-	0.015	D		
000075-15-0	Carbon disulfide (VOC)	220	E		
000056-23-5	Carbon tetrachloride (VOC)	0.026	D	30	B
000075-68-3	Chloro-1,1-difluoroethane, 1-	12,000	E		
000126-99-8	Chloro-1,3-butadiene, 2-	0.00092	D		
000108-90-7	Chlorobenzene (VOC)	11	F		
000098-56-6	Chlorobenzotrifluoride, 4-	42	F		
000075-45-6	Chlorodifluoromethane	14,000	E		

CAS #	Chemical Name*	Long-Term Air CV† (ppb)	Long-Term CV Source‡	Short-Term Air CV¶ (ppb)	Short-Term CV Source‡
000067-66-3	Chloroform (VOC)	0.0089	D	50	B
000074-87-3	Chloromethane (VOC)	44	E	200	B
000107-30-2	Chloromethyl methyl ether	0.0012	G		
000076-06-2	Chloropicrin	0.062	F		
000098-82-8	Cumene	81	E		
000057-12-5	Cyanide (CN-)	0.78	F		
000110-82-7	Cyclohexane	1,700	E		
000096-12-8	Dibromo-3-chloropropane, 1,2- (VOC)	0.021	E	0.20	B
000106-93-4	Dibromoethane, 1,2-	0.00022	D		
000074-95-3	Dibromomethane (methylene bromide) (VOC)	0.59	F		
000764-41-0	Dichloro-2-butene, 1,4-	0.00013	G		
001476-11-5	Dichloro-2-butene, cis-1,4-	0.00013	G		
000110-57-6	Dichloro-2-butene, trans-1,4-	0.00013	G		
000095-50-1	Dichlorobenzene, 1,2- (SVOC)	35	F		
000106-46-7	Dichlorobenzene, 1,4- (SVOC)	10	C	200	B
000075-71-8	Dichlorodifluoromethane (VOC)	20	F		
000075-34-3	Dichloroethane, 1,1- (VOC)	0.44	G		
000107-06-2	Dichloroethane, 1,2- (VOC)	0.0095	D		
000075-35-4	Dichloroethylene, 1,1- (VOC)	50	E	20	B
000156-60-5	Dichloroethylene, 1,2-trans- (VOC)			200	B
000078-87-5	Dichloropropane, 1,2- (VOC)	0.87	E	7.0	B
000542-75-6	Dichloropropene, 1,3- (VOC)	0.055	D	8.0	B
000077-73-6	Dicyclopentadiene	0.057	F		
000075-37-6	Difluoroethane, 1,1-	15,000	E		
000094-58-6	Dihydrosafrole	0.033	G		
000108-20-3	Diisopropyl ether	170	F		
000513-37-1	Dimethylvinylchloride	0.059	G		
000106-89-8	Epichlorohydrin	0.22	D		

CAS #	Chemical Name*	Long-Term Air CV† (ppb)	Long-Term CV Source‡	Short-Term Air CV¶ (ppb)	Short-Term CV Source‡
000106-88-7	Epoxybutane, 1,2-	6.8	E		
000141-78-6	Ethyl acetate	20	F		
000140-88-5	Ethyl acrylate	2.0	F		
000075-00-3	Ethyl chloride	3,800	E	15,000	A
000097-63-2	Ethyl methacrylate	66	F		
000100-41-4	Ethylbenzene (VOC)	60	C	2,000	B
000075-21-8	Ethylene oxide	0.00012	D	90	B
000151-56-4	Ethyleneimine	0.000085	G		
000822-06-0	Hexamethylene diisocyanate, 1,6-	0.0015	E	0.030	B
000110-54-3	Hexane, N-	20	E		
000591-78-6	Hexanone, 2- (VOC)	7.3	E		
000074-90-8	Hydrogen cyanide	0.72	E		
007439-97-6	Mercury (elemental)	0.024	C		
000126-98-7	Methacrylonitrile	11	F		
000096-33-3	Methyl acrylate	6.0	F		
000078-93-3	Methyl ethyl ketone (2-butanone) (VOC)	1,700	E		
000108-10-1	Methyl isobutyl ketone (4-methyl-2-pentanone) (VOC)	730	E		
000624-83-9	Methyl isocyanate	0.43	F		
000080-62-6	Methyl methacrylate	170	E		
025013-15-4	Methyl styrene (mixed isomers)	2.9	F		
001634-04-4	Methyl tert-butyl ether (MTBE) (VOC)	700	C	700	B
000075-09-2	Methylene chloride (VOC)	18	D	300	B
000091-20-3	Naphthalene (SVOC)	0.57	E		
000098-95-3	Nitrobenzene (SVOC)	0.0050	D		
000075-52-5	Nitromethane	0.13	G		
000079-46-9	Nitropropane, 2-	5.5	E		
000924-16-3	Nitroso-di-N-butylamine, N-	0.00028	G		
000111-84-2	Nonane, n-	4.0	F		

CAS #	Chemical Name*	Long-Term Air CV† (ppb)	Long-Term CV Source‡	Short-Term Air CV¶ (ppb)	Short-Term CV Source‡
000109-66-0	Pentane, n-	340	F		
000075-44-5	Phosgene	0.074	E		
000123-38-6	Propionaldehyde	3.5	F		
000103-65-1	Propyl benzene (VOC)	200	F		
000115-07-1	Propylene	1,800	F		
000075-56-9	Propylene oxide	0.11	D		
000100-42-5	Styrene (VOC)	200	C	5,000	A
000630-20-6	Tetrachloroethane, 1,1,1,2- (VOC)	0.020	D		
000079-34-5	Tetrachloroethane, 1,1,2,2- (VOC)	0.0070	G		
000127-18-4	Tetrachloroethylene (VOC)	0.57	D	6.0	B
000811-97-2	Tetrafluoroethane, 1,1,1,2-	19,000	E		
000109-99-9	Tetrahydrofuran	680	E		
000108-88-3	Toluene (VOC)	1,000	C	2,000	A
000076-13-1	Trichloro-1,2,2-trifluoroethane, 1,1,2-	680	F		
000120-82-1	Trichlorobenzene, 1,2,4- (SVOC)	0.28	F		
000071-55-6	Trichloroethane, 1,1,1- (VOC)	920	E	700	B
000079-00-5	Trichloroethane, 1,1,2- (VOC)	0.011	D		
000079-01-6	Trichloroethylene (VOC)	0.040	D	0.40	B
000096-18-4	Trichloropropane, 1,2,3- (VOC)	0.050	E	0.30	A
000096-19-5	Trichloropropene, 1,2,3-	0.052	F		
000121-44-8	Triethylamine	1.7	E		
000526-73-8	Trimethylbenzene, 1,2,3- (VOC)	12	E		
000095-63-6	Trimethylbenzene, 1,2,4- (VOC)	12	E		
000108-67-8	Trimethylbenzene, 1,3,5- (VOC)	12	E		
000108-05-4	Vinyl acetate (VOC)	57	E	10	B
000593-60-2	Vinyl bromide	0.69	E		
000075-01-4	Vinyl chloride (VOC)	0.044	D	30	B
000108-38-3	Xylene, m- (VOC)	23	F		

CAS #	Chemical Name*	Long-Term Air CV† (ppb)	Long-Term CV Source‡	Short-Term Air CV¶ (ppb)	Short-Term CV Source‡
000095-47-6	Xylene, o- (VOC)	23	F		
000106-42-3	Xylene, p- (VOC)	23	F		
001330-20-7	Xylenes (VOC)	23	E	600	B

Sources:

[ATSDR] Agency for Toxic Substances and Disease Registry. 2018. Health guideline and comparison value (CV) reports: April 2018. Public Health Assessment Site Tool database. Atlanta: US Department of Health and Human Services.

[USEPA] US Environmental Protection Agency. 2017. Regional screening level (RSL) residential air supporting table November 2017. Washington, DC: US Environmental Protection Agency.

ATSDR	Agency for Toxic Substances and Disease Registry
CREG	cancer risk evaluation guide
EMEG/MRL	environmental media evaluation guide/minimal risk level
CV	comparison value
ppb	parts per billion
RfC	reference concentration
SL	screening level
SVOC	semi-volatile organic compound
THI	target hazard index
TR	target risk
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound

* Blank cells in the table indicate the comparison value was not available for that chemical.

† The long-term air CV is the ATSDR Chronic EMEG/MRL, ATSDR CREG, or USEPA RfC (whichever CV is lowest) from source ATSDR [2018]. If no long-term CV value is available from source ATSDR [2018], the long-term CV is the USEPA Noncarcinogenic SL or USEPA Carcinogenic SL (whichever CV is lowest) from source USEPA [2017].

‡ Source Key:
A: ATSDR Acute EMEG/MRL
B: ATSDR Intermediate EMEG/MRL
C: ATSDR Chronic EMEG/MRL
D: ATSDR CREG

E: USEPA RfC
F: USEPA Noncarcinogenic SL THI=1
G: USEPA Carcinogenic SL TR=1E-06

¶ The short-term air CV is the ATSDR Acute EMEG/MRL or ATSDR Intermediate EMEG/MRL (whichever CV is lowest) from source ATSDR [2018].

Table 10B. Groundwater and Soil Gas Vapor Intrusion Comparison Values (5 pages)

CAS #	Chemical Name*	Long-Term Groundwater VICV† (ppb)	Short-Term Groundwater VICV (ppb)	Long-Term Soil Gas VICV‡ (ppb)	Short-Term Soil Gas VICV (ppb)
000075-07-0	Acetaldehyde	92		8.3	
000067-64-1	Acetone (VOC)	9,100,000	9,100,000	430,000	430,000
000075-86-5	Acetone cyanohydrin	7,400,000		20	
000075-05-8	Acetonitrile	26,000		1,200	
000107-02-8	Acrolein	1.7	8.0	0.29	1.3
000107-13-1	Acrylonitrile	1.2	18,000	0.23	3,300
000107-05-1	Allyl chloride	0.71		11	
011104-28-2	Aroclor 1221	0.069		0.021	
011141-16-5	Aroclor 1232	0.021		0.021	
000103-33-3	Azobenzene	7.8		0.14	
000071-43-2	Benzene (VOC)	0.18	26	1.3	200
000100-44-7	Benzyl chloride	0.65		0.37	
000092-52-4	Biphenyl, 1,1'-	5.3		2.2	
000111-44-4	Bis(2-chloroethyl)ether (SVOC)	0.75	29,000	0.017	670
000542-88-1	Bis(chloromethyl)ether	0.000019	1.7	0.00011	10
000107-04-0	Bromo-2-chloroethane, 1-	0.022		0.027	
000108-86-1	Bromobenzene (VOC)	92		310	
000074-97-5	Bromochloromethane (VOC)	130		260	
000075-27-4	Bromodichloromethane (VOC)	0.13		0.37	
000074-83-9	Bromomethane (VOC)	4.3	170	43	1,700
000106-99-0	Butadiene, 1,3-	0.0050		0.50	
000075-15-0	Carbon disulfide (VOC)	370		7,300	
000056-23-5	Carbon tetrachloride (VOC)	0.023	27	0.87	1,000
000075-68-3	Chloro-1,1-difluoroethane, 1-	5,000		400,000	
000126-99-8	Chloro-1,3-butadiene, 2-	0.00040		0.031	
000108-90-7	Chlorobenzene (VOC)	87		370	
000098-56-6	Chlorobenzotrifluoride, 4-	30		1,400	

CAS #	Chemical Name*	Long-Term Groundwater VICV† (ppb)	Short-Term Groundwater VICV (ppb)	Long-Term Soil Gas VICV‡ (ppb)	Short-Term Soil Gas VICV (ppb)
000075-45-6	Chlorodifluoromethane	8,400		470,000	
000067-66-3	Chloroform (VOC)	0.059	330	0.30	1,700
000074-87-3	Chloromethane (VOC)	120	550	1,500	6,700
000107-30-2	Chloromethyl methyl ether	0.097		0.040	
000076-06-2	Chloropicrin	0.74		2.1	
000098-82-8	Cumene	170		2,700	
000057-12-5	Cyanide (CN-)	0.79		26	
000110-82-7	Cyclohexane	280		57,000	
000096-12-8	Dibromo-3-chloropropane, 1,2- (VOC)	3.5	33	0.70	6.7
000106-93-4	Dibromoethane, 1,2-	0.0083		0.0073	
000074-95-3	Dibromomethane (methylene bromide) (VOC)	18		20	
000764-41-0	Dichloro-2-butene, 1,4-	0.00037		0.0043	
001476-11-5	Dichloro-2-butene, cis-1,4-	0.0048		0.0043	
000110-57-6	Dichloro-2-butene, trans-1,4-	0.0048		0.0043	
000095-50-1	Dichlorobenzene, 1,2- (SVOC)	450		1,200	
000106-46-7	Dichlorobenzene, 1,4- (SVOC)	100	2,000	330	6,700
000075-71-8	Dichlorodifluoromethane (VOC)	1.4		670	
000075-34-3	Dichloroethane, 1,1- (VOC)	1.9		15	
000107-06-2	Dichloroethane, 1,2- (VOC)	0.20		0.32	
000075-35-4	Dichloroethylene, 1,1- (VOC)	47	19	1,700	670
000156-60-5	Dichloroethylene, 1,2-trans- (VOC)		520		6,700
000078-87-5	Dichloropropane, 1,2- (VOC)	7.5	61	29	230
000542-75-6	Dichloropropene, 1,3- (VOC)	0.38	55	1.8	270
000077-73-6	Dicyclopentadiene	0.022		1.9	
000075-37-6	Difluoroethane, 1,1-	18,000		500,000	
000094-58-6	Dihydrosafrole	66		1.1	
000108-20-3	Diisopropyl ether	1,600		5,700	
000513-37-1	Dimethylvinylchloride	0.013		2.0	

CAS #	Chemical Name*	Long-Term Groundwater VICV† (ppb)	Short-Term Groundwater VICV (ppb)	Long-Term Soil Gas VICV‡ (ppb)	Short-Term Soil Gas VICV (ppb)
000106-89-8	Epichlorohydrin	180		7.3	
000106-88-7	Epoxybutane, 1,2-	920		230	
000141-78-6	Ethyl acetate	3,700		670	
000140-88-5	Ethyl acrylate	140		67	
000075-00-3	Ethyl chloride	8,400	33,000	130,000	500,000
000097-63-2	Ethyl methacrylate	2,800		2,200	
000100-41-4	Ethylbenzene (VOC)	190	6,200	2,000	67,000
000075-21-8	Ethylene oxide	0.020	15,000	0.0040	3,000
000151-56-4	Ethyleneimine	0.17		0.0028	
000822-06-0	Hexamethylene diisocyanate, 1,6-	0.76	15	0.050	1.0
000110-54-3	Hexane, N-	0.27		670	
000591-78-6	Hexanone, 2- (VOC)	1,900		240	
000074-90-8	Hydrogen cyanide	130		24	
007439-97-6	Mercury (elemental)	0.068		0.80	
000126-98-7	Methacrylonitrile	1,100		370	
000096-33-3	Methyl acrylate	740		200	
000078-93-3	Methyl ethyl ketone (2-butanone) (VOC)	730,000		57,000	
000108-10-1	Methyl isobutyl ketone (4-methyl-2-pentanone) (VOC)	130,000		24,000	
000624-83-9	Methyl isocyanate	11		14	
000080-62-6	Methyl methacrylate	13,000		5,700	
025013-15-4	Methyl styrene (mixed isomers)	27		97	
001634-04-4	Methyl tert-butyl ether (MTBE) (VOC)	29,000	29,000	23,000	23,000
000075-09-2	Methylene chloride (VOC)	140	2,300	600	10,000
000091-20-3	Naphthalene (SVOC)	32		19	
000098-95-3	Nitrobenzene (SVOC)	5.1		0.17	
000075-52-5	Nitromethane	110		4.3	
000079-46-9	Nitropropane, 2-	1,100		180	
000924-16-3	Nitroso-di-N-butylamine, N-	0.52		0.0093	

CAS #	Chemical Name*	Long-Term Groundwater VICV† (ppb)	Short-Term Groundwater VICV (ppb)	Long-Term Soil Gas VICV‡ (ppb)	Short-Term Soil Gas VICV (ppb)
000111-84-2	Nonane, n-	0.029		130	
000109-66-0	Pentane, n-	6.7		11,000	
000075-44-5	Phosgene	0.11		2.5	
000123-38-6	Propionaldehyde	1,200		120	
000103-65-1	Propyl benzene (VOC)	470		6,700	
000115-07-1	Propylene	220		60,000	
000075-56-9	Propylene oxide	39		3.7	
000100-42-5	Styrene (VOC)	1,800	44,000	6,700	170,000
000630-20-6	Tetrachloroethane, 1,1,1,2- (VOC)	0.20		0.67	
000079-34-5	Tetrachloroethane, 1,1,2,2- (VOC)	0.47		0.23	
000127-18-4	Tetrachloroethylene (VOC)	0.79	8.3	19	200
000811-97-2	Tetrafluoroethane, 1,1,1,2-	9,300		630,000	
000109-99-9	Tetrahydrofuran	240,000		23,000	
000108-88-3	Toluene (VOC)	3,700	7,400	33,000	67,000
000076-13-1	Trichloro-1,2,2-trifluoroethane, 1,1,2-	32		23,000	
000120-82-1	Trichlorobenzene, 1,2,4- (SVOC)	4.8		9.3	
000071-55-6	Trichloroethane, 1,1,1- (VOC)	1,300	1,000	31,000	23,000
000079-00-5	Trichloroethane, 1,1,2- (VOC)	0.33		0.37	
000079-01-6	Trichloroethylene (VOC)	0.099	0.99	1.3	13
000096-18-4	Trichloropropane, 1,2,3- (VOC)	3.6	21	1.7	10
000096-19-5	Trichloropropene, 1,2,3-	0.072		1.7	
000121-44-8	Triethylamine	280		57	
000526-73-8	Trimethylbenzene, 1,2,3- (VOC)	67		400	
000095-63-6	Trimethylbenzene, 1,2,4- (VOC)	48		400	
000108-67-8	Trimethylbenzene, 1,3,5- (VOC)	33		400	
000108-05-4	Vinyl acetate (VOC)	2,700	480	1,900	330
000593-60-2	Vinyl bromide	1.4		23	
000075-01-4	Vinyl chloride (VOC)	0.039	26	1.5	1,000

CAS #	Chemical Name*	Long-Term Groundwater VICV† (ppb)	Short-Term Groundwater VICV (ppb)	Long-Term Soil Gas VICV‡ (ppb)	Short-Term Soil Gas VICV (ppb)
000108-38-3	Xylene, m- (VOC)	78		770	
000095-47-6	Xylene, o- (VOC)	110		770	
000106-42-3	Xylene, p- (VOC)	82		770	
001330-20-7	Xylenes (VOC)	85	2,200	770	20,000

* Blank cells in the table indicate the vapor intrusion comparison value was not available for that chemical.

† Groundwater VICV = Air CV / [(Henry's Law Constant × USEPA Groundwater Attenuation Factor × Unit Conversion Factor)], where the USEPA Groundwater Attenuation Factor (AF_{USEPA}) is 0.001 and the Unit Conversion Factor is 1,000 liters per cubic meter (L/m^3). Note, the air CV values and sources are found in Table 9B, Appendix B, of this report.

‡ Soil Gas VICV = Air CV / USEPA Soil Gas Attenuation Factor, where the USEPA Soil Gas Attenuation Factor is 0.03. Note, the air CV values and sources are found in Table 9B, Appendix B, of this report.

AF attenuation factor
CV comparison value
L/m^3 liters per cubic meter
ppb parts per billion
SVOC semi-volatile organic compound
USEPA United States Environmental Protection Agency
VICV vapor intrusion comparison value
VOC volatile organic compound

Appendix C. Non-Residential Attenuation Factor Derivation

As part of its analysis, the Agency for Toxic Substances and Disease Registry (ATSDR) will derive groundwater-to-air non-residential attenuation factors (AFs) to estimate building-specific indoor air concentrations for periods when only groundwater contaminant concentrations are available for these buildings. Note that these estimated AFs are conservative.

As stated in Section 3.3.1 of the main text, ATSDR will estimate indoor air contaminant concentrations using groundwater-to-air AFs under certain conditions. These conditions include that the building must have representative measured groundwater data allowing for the calculation of a 95% upper confidence level of the mean (95% UCL) value and/or have simulated groundwater concentrations. In addition, for the derivation ATSDR needs the building foundation area (A_{Bldg}) in square meters, the interior height of the building (H_{Bldg}) in meters, and the air exchange rate in the building (ACH_{Bldg}). At this time, ATSDR has the building foundation area (i.e., building footprint) for all buildings on the base, but will work with U.S. Marine Corps Base (MCB) Camp Lejeune to obtain the interior heights and air exchange rates for buildings.

To obtain a building-specific groundwater-to-air non-residential AF, ATSDR must first derive an estimate of the subslab attenuation factor for the building. Subslab attenuation factors can be calculated based upon academic considerations. For example, a simple mass balance analysis, assuming a well-mixed interior volume and steady-state conditions, indicates that the subslab soil gas attenuation factor (AF_{ss}) can be expressed as the ratio of the soil gas entry rate (Q_{soil}) to the building ventilation rate (Q_{Bldg}) [Song et al. 2011] for cases where there is no background contribution to the indoor air concentration.

Equation 1 $$AF_{ss} = C_{IA} / C_{ss} = Q_{soil} / Q_{Bldg}$$

In Equation 1, C_{IA} represents the concentration of vapor-forming substance in indoor air arising from vapor intrusion, C_{SS} represents the concentration of vapor-forming substance in sub-slab soil gas, and other symbols are defined previously. The building ventilation rate can be calculated by:

Equation 2a $$Q_{Bldg} = V_{Bldg} \times ACH_{Bldg}$$

Equation 2b $$Q_{Bldg} = H_{Bldg} \times A_{Bldg} \times ACH_{Bldg}$$

where V_{Bldg} is the interior volume of the building in cubic meters and other symbols are defined previously. Equations 1 and 2a were employed to calculate theoretical values of the subslab attenuation factor for residential buildings, as described in Section 5.1 of the U.S. Environmental Protection Agency (USEPA) vapor intrusion database report [USEPA 2012]. Under the reasonable assumption that the foundation in a non-residential (non-res) building is as leaky as one in a residential (res) building (i.e., the soil gas entry rates per unit area are equal), the following relationship is proposed:

Equation 3 $$\text{res } Q_{soil} / \text{non-res } Q_{soil} = \text{res } A_{Bldg} / \text{non-res } A_{Bldg}$$

Combining Equations 1, 2b and 3, one obtains:

Equation 4
$$\frac{\text{non-res } AF_{ss}}{\text{res } AF_{ss}} = \frac{\text{non-res } Q_{soil} / \text{non-res } Q_{Bldg}}{\text{res } Q_{soil} / \text{res } Q_{Bldg}} = \frac{\text{res } H_{Bldg} \times \text{res } ACH_{Bldg}}{\text{non-res } H_{Bldg} \times \text{non-res } ACH_{Bldg}}$$

Building-related inputs that merit consideration are as follows:

Table C1. Comparison of Size Characteristics for Residential and Some Commercial Buildings

Input Parameter and Units	Value and Source for Residential Building	Value and Source for Commercial Buildings, Other Than Warehouses and Enclosed Malls
ACH_{Bldg} (1/hour), 10th percentile	0.18 [USEPA 2011, Table 19-1]	0.6 [USEPA 2011, Table 19-27]
H_{Bldg} (feet)	8-feet ceiling height [EPA 2011, assumed value]	12-feet ceiling height [USEPA 2011, assumed value]

Of note, using the input values in Table C1, Equation 4, and the USEPA-recommended subslab soil gas attenuation factors for residential buildings (res AF_{ss} = 0.03; USEPA 2015), **0.006** is obtained as an estimate of the generic, subslab attenuation factor for commercial buildings (non-res AF_{ss}) other than warehouses and enclosed malls. Although this calculated non-res AF_{ss} for commercial building can potentially be applicable for some MBC Camp Lejeune buildings, several of the buildings on the base are warehouses. Therefore, ATSDR will use residential inputs from Table C1, Equation 4, the USEPA-recommended subslab soil gas attenuation factors for residential buildings (res AF_{ss} = 0.03; USEPA 2015), and available building-specific data from MCB Camp Lejeune (i.e., ACH_{Bldg} and H_{Bldg}), to calculate building-specific subslab non-residential attention factors (non-res AF_{ss}).

If the assumption holds that the only difference between residential and non-residential buildings is the building characteristics (ACH_{Bldg} and H_{Bldg}), semi-site-specific groundwater attenuation factors for non-residential buildings (non-res AF_{gw}) can be calculated by a simple ratio:

Equation 5
$$\text{non-res } AF_{gw} = (\text{non-res } AF_{ss} / \text{res } AF_{ss}) \times \text{res } AF_{gw}$$

In Equation 5, ATSDR will use the USEPA-recommended values of the sub-slab attenuation factors for residential buildings (res AF_{ss} = 0.03; USEPA 2015), the UAEPA-recommended groundwater attenuation factor for residential buildings (AF_{gw} = 0.001; EPA 2015), and the calculated building-specific subslab non-residential attention factor (non-res AF_{ss}), to calculate building-specific groundwater attenuation factors for non-residential buildings (non-res AF_{gw}). Note, using the 0.006 calculated non-res AF_{ss} for commercial buildings yields a non-res AF_{gw} of **0.0002**.

References

Song S, Ramacciotti FC, Schnorr BA, et al. 2011. Evaluation of EPA's empirical attenuation factor database. EM, Air & Waste Management Association. February.

[USEPA] US Environmental Protection Agency. 2011. Exposure factors handbook. Washington, DC: U.S. Environmental Protection Agency. EPA/600/R-09/052F.

[USEPA] US Environmental Protection Agency. 2012. Vapor intrusion database: evaluation of attenuation factors for chlorinated volatile organic compounds and residential buildings. Washington, DC: U.S. Environmental Protection Agency. EPA 530-R-10-002.

[USEPA] US Environmental Protection Agency. 2015. OSWER Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor Sources to indoor air (OSWER Publication 9200.2-154). Washington, DC: U.S. Environmental Protection Agency.

Appendix D. External Peer Reviewer Comments and ATSDR Responses

ATSDR received the following comments from six independent peer reviewers on the *Public Health Response Work Plan, Evaluation of Potential Exposures from Vapor Intrusion, U.S. Marine Corps Base Camp Lejeune, North Carolina.*

Reviewer	***Reviewer Comment***	***ATSDR Response***
1. Does the Work Plan provide a scientifically sound approach for evaluating exposures and associated health effects from vapor intrusion at U.S. Marine Corps Base Camp Lejeune?		
1	Yes, I believe the scientific approach presented in the Work Plan is a sound approach to estimate areas and building with potential exposures and associated health effects at Camp Lejeune. The inclusion of historical data and various environmental sample types are substantial improvements on previous methods, which incorporated only relatively recent groundwater data. The variability of variability in parameters in the Johnson and Ettinger model is well recognized in this Work Plan and the approach used to estimate the uncertainty in attenuation from the subsurface is a sound approach that should capture the range or distribution of potential site-specific attenuation factors.	Thank you for the confirmation.
2	Yes.	Thank you for the confirmation.
3	The approach is scientifically sound but there are aspects of the conceptual site model that are not included in the analysis as commented on below. Additionally, it is considered important to separate the estimation of receptor concentrations, from the data quality and quantity used to make those estimates. A more uncertain estimate or incomplete data should be treated separately from the receptor estimates. An example of where this could be problematic is where there is a low estimated indoor air concentration below standards but other factors related to data quality and quantity increase the score and apparent risk. This is considered to be an approach that is potentially flawed. The more appropriate conclusion in this example is that receptor prediction should be viewed separately from the data quality and quantity and potential need for refined analysis or additional data.	For Section 3.1, a computer application will compile data from the VI database to complete the Prioritization Scheme. Table 8B, Appendix B, will display the results on a contaminant-by-contaminant basis for each building. For example, ATSDR will know whether contaminants are present in groundwater and indoor air (i.e., noted by the points in the columns for the results of these media), but not soil gas (i.e., noted by the lack of points in the column for the soil gas medium). ATSDR staff will also be able to review the specific table factor outputs (like frequency, timeframe, concentration, etc.) for each chemical that go into the results summarized in Table 8B, Appendix B. Although the computer application will not flag these results, review of the output will show potential inconsistencies that ATSDR will consider when placing a building within one of the VI risk categories. Note that the Prioritization Scheme (Section 3.1) is only the first step ATSDR will take to focus its evaluation on buildings of greatest concern for potential VI impacts. In Section 3.2, ATSDR will compile additional sources of information that might aid in focusing ATSDR's VI evaluation as well as assist in determining why some of the data appear inconsistent.

Reviewer	Reviewer Comment	ATSDR Response
4	As I understand them, the risk assessment and related procedures that comprise the public health evaluation, once indoor air exposures have been estimated, (e.g., comparing exposure estimates to acute and chronic effects levels summarized in the toxicological literature) are appropriate and consistent with those used routinely by ATSDR for its public health assessment program.	Correct. The public health evaluation will follow standard procedures outlined in the ATSDR Public Health Assessment Guidance Manual [ATSDR 2005], Guidance Manual for the Assessment of Joint Toxic Action of Chemical Mixtures [ATSDR 2004], and technical supplement Evaluating Vapor Intrusion Pathways [ATSDR 2016].
	In Comment #4, I offer some constructive criticism about the proposed methods for estimating vapor intrusion exposures and recommend an alternative approach that should be more scientifically sound.	Please see ATSDR's responses later in this table to the specific proposed methods and alternative approach outlined in Comment #4 by Reviewer 4.

	For a few work components, the work plan lacks sufficient, specific information about means and methods, which precludes an evaluation of scientific soundness. So, for example: • It is not apparent how ATSDR "will use the VI database to distinguish between the contributions of VI contaminants and those from indoor and outdoor sources" – see Section 4. For some time-periods and buildings of interest, indoor sources of vapors may include non-consumptive uses of contaminated drinking water, during which vapors volatilize from drinking water (e.g., showering, bathing, washing dishes, washing clothes). • It is not apparent how ATSDR will "determine effectiveness of soil vapor mitigation systems installed in buildings on the base". The work plan states only that ATSDR will use "more recent data" – see Section 3.3.2. • It is not apparent how buildings or areas will be determined to have "high potential VI risk", "medium potential VI risk", or "no apparent VI risk", based upon the proposed scoring system that comprises the prioritization scheme. The work plan states merely that "ATSDR will consider the scores". • It is not apparent how ATSDR will use "Holton [2013] as a guide to consider factors affecting temporal variability." Inasmuch as Holton et al. [2013][29] pertains to a house in which "conduit gas intrusion" rather than soil gas intrusion, was found to be the primary mechanisms of vapor intrusion, it is also not clear that Holton [2013] is even relevant to housing stock that are subject only or primarily to soil gas intrusion.	ATSDR provided as much detail as possible in the work plan. With regard to each of the Reviewer's bullets: • At the building level, the agency will gather available information on potential indoor and outdoor sources. As stated in Section 3.3.2 of the work plan (see specific tasks main bullet 3, sub-bullet 2), "A table will provide the conclusions for each building the agency evaluates. This table will also summarize information such as building characteristics (e.g., use and mitigation system operation) and whether there are potential background (outdoor and/or indoor) air sources, air and/or biosparge systems, USTs, shallow groundwater plumes, and free product sources in the area." For clarification, ATSDR will add this text as a sub-sub-bullet to the above text, "The agency will not quantitatively distinguish contributions from different sources, but will use information in the database to qualitatively acknowledge those contributions in our building-specific conclusions." Of note, indoor vapors from non-consumptive uses of contaminated drinking water were evaluated in ATSDR's revised drinking water PHA [ATSDR 2017]. The conclusions ATSDR reaches about each building will consider these indoor vapors, when appropriate. • Using more recent data, ATSDR will evaluate the public health implications of current indoor air exposures to occupants in buildings with vapor intrusion mitigations systems. To further explain, the agency added a sub-sub-bullet to Section 3.3.2 of the work plan under specific tasks main bullet 3, sub-bullet 4, "If the agency's evaluation finds indoor air contaminants in a building are below levels expected to harm health, the agency will conclude the system is effective at reducing indoor air contaminant concentrations for that building." • To determine "high potential VI risk", "medium potential VI risk", etc., ATSDR will use technical expertise and professional judgment to evaluate the combination of contaminant scores (compiled from Tables 3B–7B, Appendix B) and building-specific factors (compiled from Table 2B, Appendix B) when determining each building's placement in one of the VI risk categories. • Because vapor intrusion tends to have active and dormant phases, ATSDR will use concepts similar to those in Holton [2013] to qualitatively

Reviewer	Reviewer Comment	ATSDR Response
		consider the likelihood that indoor air samples would capture an exceedance of a comparison value (CV). In the Holton study, when the mean concentration is twice the CV, there is a 54% chance the CV exceedance would be detected in a summer and winter sample set; there is a 72% chance if the mean is five times the CV. In the Holton study conceptual site model, vapor intrusion occurred primarily through a lateral drain rather than through soil gas intrusion. Since vapor intrusion from soil gas is usually diffusion limited, "conduit gas intrusion" is likely convective and may be more susceptible to fluctuation (less steady state).The other residence EPA has been studying (Indiana) found sewer gas intrusion. It is unknown how prevalent conduit gas intrusion is over soil gas intrusion. If soil gas intrusion into structures fluctuates less than through conduits, there could be less chance of capturing data during an inactive phase, i.e. the chances of detecting an exceedance would be greater than 54% with the mean twice the CV and a summer and winter sample. For reasonable maximum exposure estimation, 95th upper confidence limits (UCLs) are usually recommended in other media. ATSDR will take this into consideration when evaluating uncertainties and limitations of the data. Note also that at Camp Lejeune underground utilities might allow contaminants to travel unusually long distances to occupied buildings, beyond the 100 feet commonly used for screening. For its area investigation, ATSDR will consider potential underground utilities (e.g., sewer, water lines) and whether the agency should expand the evaluation to include other buildings beyond 100 feet.
5	Limitations to the scientific defensibility of the proposed approach to assess potential vapor intrusion exposures and associated health effects are described below. The adequacy of the proposed approach is dependent on how well the uncertainties associated with the investigation process are characterized and summarized in the report.	Reviewer 5's specific comments are documented later in this table, along with ATSDR's responses to those comments.

[29] Holton, C., H. Luo, P. Dahlen, K. Gorder, E. Dettenmaier, and P. C. Johnson. 2013. Temporal variability of indoor air concentrations under natural conditions in a house overlying a dilute chlorinated solvent groundwater plume. *Environmental Science & Technology* 47:13347-13354.

Reviewer	Reviewer Comment	ATSDR Response
6	Overall, I think the Work Plan provides a scientifically sound approach for evaluating potential exposures and health effects. My review indicates that the Work Plan outlines an approach to accomplish two primary tasks: (1) identify how buildings will be evaluated to be included in the vapor intrusion (VI) public health assessment (PHA); and (2) describe how the identified buildings will be ranked in order of priority. Given the enormous amount of data that is available, it is clear that a database and method was needed to meet the two tasks (or objectives) above. However, I do have a few questions and concerns that should be addressed prior to finalizing the Work Plan.	Thank you for your comment.
	First, while the pieces of the approach appear to be valid, it is very difficult to understand how they all fit together. In some cases, it seems like the same data are being used in a few different ways. This may be appropriate, but the text is not detailed enough to determine. I would strongly recommend that ATSDR provide a flow chart or diagram to explain the overall process for the Prioritization Scheme (see more detailed comments below) including how each of the pieces fit together. For example, it is unclear how the criteria presented in Table 2B will be integrated with the rest of the Tables in Appendix B since there are different scales being used.	After a careful review of the work plan in response to this comment, ATSDR noticed the simulated datasets were being used in a few ways that overlapped. Therefore, ATSDR will not use the simulated dataset to estimate shallow groundwater plumes, but instead use preliminary shallow groundwater plume data provided by MCB Camp Lejeune. To show how the pieces of the approach fit together, ATSDR added three figures to Appendix A of the work plan: Figure 2A (ATSDR's Prioritization Scheme Directory Structure), Figure 3A (ATSDR's Prioritization Scheme High Level Data Flow), and Figure 4A (ATSDR's Priority Scheme Concurrency Diagram). Regarding the example provided by Reviewer 6, ATSDR will use technical expertise and professional judgement to evaluate the contaminant scores (compiled as *numerical scores* from Tables 3B–7B, Appendix B) and building factors (compiled as *text* from Table 2B, Appendix B) when determining each building's placement in one of the VI risk categories.

Reviewer	Reviewer Comment	ATSDR Response
	Second, the Work Plan does rely on other data or information that this reviewer has not reviewed in detail. Specifically, this includes the historical data modeling conducted by Georgia Institute of Technology and ATSDR. The accuracy and validity of these data modeling exercises will be critical to ensuring that the predicted indoor air concentrations are reasonable and scientifically supportable. In any risk assessment, the exposure point concentration is usually the most sensitive input and determinant on whether there is a potential risk or hazard at a site. If there are flaws in the modeling, it is likely to lead to flaws in the identification of historical risks associated with vapor intrusion.	ATSDR acknowledges there are limitations in the agency's evaluation of VI exposures at MCB Camp Lejeune. Section 4 (Limitations) discusses several limitations in this evaluation including the uncertainty inherent in the agency's and GA Tech's historical reconstruction modeling. To address this comment, ATSDR also added clarification to two sections in the work plan: • Section 3.1.2, second paragraph, "Before using these data in the VI PHA, ATSDR will also determine whether the simulated contaminant concentration data for Model Layer 1 are similar to the measured contaminant concentration data for the same locations and time frames." • Section 4, main bullet 2, "For the VI PHA, ATSDR plans to compare simulated shallow groundwater results for Model Layer 1 with measured shallow groundwater results for similar locations and time frames to determine how well the simulated concentrations are similar to the measured concentrations (most likely using a Kendall's Tau rank correlation coefficient, t-test, and/or Wilcoxon signed rank test.)"
	Third, the current Work Plan does not address the concern with the CH2M approach that sufficient numbers of samples were collected to fully address the VI pathway. As data gaps are identified, it is possible to add data collection to the data analysis steps?	The VI PHA will evaluate available information; the agency will not perform data collection. However, if ATSDR identifies critical data gaps (i.e., information is missing that is critical to making an appropriate public health call), the agency will recommend additional sampling efforts be conducted by other entities. Note though, as a public health advisory agency, ATSDR has no authority to enforce our recommendations. The agency's goal is to develop strong partnerships with other entities and work with them to implement our public health recommendations, but sometimes decisions are made outside of the agency's control.
2. Does the planned approach adequately incorporate the pertinent lines of evidence that should be considered in a vapor intrusion evaluation?		
1	I found the lines of evidence presented in the Work Plan to be sufficient. The addition of other ancillary lines of evidence such as tree sampling may inform and improve certainty of risk estimates (see comment #3).	Please see ATSDR's responses outlined later in this table in Comment #3 by Reviewer 1.

Reviewer	Reviewer Comment	ATSDR Response
2	Yes, although it should be noted that inhalation exposure from groundwater/drinking water supply via showering, dish washing, etc. was calculated separately in the January 20, 2017 Public Health Assessment. All inhalation exposures should be combined before calculating the potential health effects.	At the building level, ATSDR will qualitatively acknowledge contributions from inhalation exposure from past groundwater/drinking water supply via showering, dish washing, etc. Because calculating historical indoor air estimates for VI will introduce a large degree of uncertainty, the agency does not expect to combine past estimated VI inhalation exposures with the estimated inhalation exposures from groundwater/drinking water presented in the January 20, 2017 Public Health Assessment.
3	The lines of evidence as understood are measured indoor air concentrations, and predicted indoor air concentrations from soil gas and groundwater data. These are the main lines of evidence for evaluating exposures to receptors. Additional factors or lines of evidence could be evaluated for understanding the conceptual site model such as building, climatic and weather related factors. A key gap or limitation is considered the potential for petroleum hydrocarbons to biodegrade. Consideration of biodegradation through a vertical screening distance approach or application of bioreduction factors is recommended.	The conceptual model includes many lines of evidence, such as building-specific information outlined in Sections 3.1.3 and 3.2.2 of the work plan. In Section 3.1, ATSDR states the VI PHA will use the conservative assumption of no biodegradation. The agency modified the statement to indicate that the Prioritization Scheme will use the conservative assumption of no biodegradation. However, ATSDR will consider guidance, such as the USEPA's petroleum vapor intrusion guidance [USEPA 2015b], in the agency's building-specific public health evaluations (Section 3.3.2) with regard to fate and transport factors such as for biodegradation. For example, ATSDR will evaluate factors such as available information on building dimensions, depths to groundwater, contaminant concentrations, area of paving around buildings, and soil properties to assess the potential for biodegradation in high priority buildings where petroleum compounds are the primary concern.
4	The planned approach identifies a number of lines of location- and building-specific evidence that have been or are to be compiled in a project database.	Thank you for your comment.
	If by "adequately incorporate" you mean to ask whether other lines of evidence should also be collected and validated, the answer is 'yes, maybe.' For example, to make greater use of a mathematical model for purposes of estimating vapor exposures, as recommended by this reviewer, additional information about soil type, physical parameters of the soil, depth to ground water, and other variables that influence location-specific potential for soil gas intrusion may warrant collection.	ATSDR intends to use the Johnson and Ettinger (J&E) model to estimate reasonable ranges of attenuation factors (AFs) based on a series of site-specific scenarios. Available location-specific information will be used including soil, groundwater, and building characteristics to develop the VI PHA.

Reviewer	Reviewer Comment	ATSDR Response
	If by "adequately incorporate" you mean to ask whether each line of evidence will be incorporated in a scientifically appropriate manner, given the stated purpose for the respective analysis or activity, then the answer is 'no' or 'sometimes', as described further elsewhere in these comments (e.g., reservations expressed below about the proposed prioritization scheme).	Please see ATSDR's responses to comments by Reviewer 4 later in this table.
5	The work plan does good job in collecting multiple lines of evidence for the vapor intrusion pathway evaluation, but there is insufficient detail provided to explain how these different lines of evidence will be used to assess the public health implications of the vapor intrusion pathway (e.g., how the different lines of evidence will be weighted). Discussion regarding the multiple-lines-of-evidence evaluation appears to be limited to Section 3.3.2, third main bullet).	The agency added a sub-bullet clarifying that, "As described in ATSDR Public Health Assessment Guidance Manual [ATSDR 2005] and the technical supplement Evaluating Vapor Intrusion Pathways [ATSDR 2016a], ATSDR staff will use both technical expertise and professional judgment to evaluate multiple lines of evidence in its assessment of the public health implications of the vapor intrusion pathway."
	The Historical Indoor Air Exposures Estimation (Section 3.3.1) does not include an assessment based on soil gas data. I see no reason to exclude this line of evidence from the evaluation (or the work plan should explain why the soil gas data are not included here).	The agency added information to the first paragraph of this section clarifying that, "Unlike groundwater data, there are very limited soil gas data available to assist with historical indoor air exposure estimates. Because there are so few samples, ATSDR does not expect the limited soil gas data from the past to be representative over space and time." Therefore, ATSDR is using these data in the Prioritization Scheme and as a line of evidence for potential VI risk, but not to estimate historical indoor air exposures.

Reviewer	Reviewer Comment	ATSDR Response
6	The planned approach incorporates information about building conditions, building occupancy, and proximity to chemicals in groundwater as the primary lines of evidence for evaluation. A few other items should be considered as available: 1. While the number of soil vapor samples near a building are considered, soil vapor itself is not used to pull in or screen out any buildings. Soil vapor should be considered as another line of evidence when determining if a building is of high or low potential concern for VI. 2. There is no discussion of evaluation of preferential pathways. Section 3.2.2 indicates that utility lines will be included in GIS maps, but there is no indication of how this information will be used. 3. For existing building, it may be helpful to look more closely at building condition. If sumps or cracks are present, that may pose a greater risk, especially for those buildings without indoor air data. 4. There is no discussion of available soil data and how that media may affect or influence indoor air concentrations.	The primary lines of evidence are building-specific factors, shallow groundwater data, indoor air data, and soil gas data. 1. For the Prioritization Scheme, in Section 3.1.1 (main bullet 3, sub-bullet 4), ATSDR defines *soil gas* as any data referred to as "soil gas," "soil vapor," "subslab soil gas," or "vapor" within the source documents. Soil gas is included as a line of evidence for determining building VI risk (see Table 6B, Appendix B). 2. Underground utilities might allow contaminants to travel unusually long distances to occupied buildings, beyond the 100 feet commonly used for screening. For its area investigation, ATSDR will consider potential underground pathways (e.g., sewer, water lines) and whether the agency should expand the evaluation to include other buildings beyond 100 feet. 3. Although ATSDR agrees that building condition can impact VI, this type of information was not available to include in the VI database. However, ATSDR added building "condition" to the list of items to ask MCB Camp Lejeune staff about once the agency has focused the investigation (see Section 3.3.2, specific tasks main bullet 2, sub-bullet 4). 4. From the historical modeling effort, ATSDR has soil characteristic data for some areas of the base, and will incorporate this information into the J&E model runs. Subsurface properties of the soil will be compiled from United States Department of Agriculture (USDA) maps for use in the J&E model as well.
3. Does the site-specific Prioritization Scheme (Section 3.1) and Area Investigation (Section 3.2.2) adequately focus the evaluation on buildings in areas of the base of greatest likelihood for potential vapor intrusion impacts?		

Reviewer	Reviewer Comment	ATSDR Response
1	In general, the approach outlined in sections 3.1 and 3.2.2 provide sufficient focus to areas with the greatest probability of potential vapor intrusion. The attenuation factors from the USEPA of 0.001 and 0.03 for groundwater and soil gas, respectively, may be too high low in areas where the groundwater or source is very shallow (less than 5 feet according to the USEPA). These attenuation factors may need to vary in space if there are large areas or times when depths to groundwater are less than 5 feet.	Water tables are influenced by many factors, including topography, geology, weather, ground cover, and land use. Groundwater levels change for many reasons, such as following significant precipitation events and during well pumping. In Section 3.2.2, ATSDR indicates that to the extent data are available such as average depth to groundwater in different areas of the base, the agency will consider them in the VI evaluation. ATSDR is aware that the depth to groundwater may be less than 5 ft for some portions of the base during certain timeframes. ATSDR's historic modeling effort simulated transient-state groundwater level data corresponding to monthly intervals (e.g., January 1951 through December 2008) that included fluctuations of the water-level due to pumping, recharge, and groundwater flow among other factors for the HPIA and Tarawa Terrace. The agency can also calculate a general depth to groundwater from ground elevation data available for the U.S. As appropriate, ATSDR can consider depth to groundwater (as well as distance to an LNAPL source) in its estimates of historical indoor air concentrations by assuming an attenuation factor of 1 for shallow groundwater. This information was added to the work plan in Section 3.3.1. Note that ATSDR had not originally planned to use depth to groundwater in the Prioritization Scheme (Section 3.1). However, in response to this comment, ATSDR will update the sensitivity analyses section to add a bullet that the agency will assume no attenuation is occurring for one of the analyses; that is, change the attenuation factor to 1 for shallow groundwater and soil gas to see the effect on the scheme.
	In Section 3.2.2 (Area Investigation), if information is available on soil type (e.g., sandy, clayey, etc) then the union of areas with permeable soils (e.g., gravels, sands, etc) with the groundwater plume could also indicate areas with higher potential VI risk. I think the union is important here, because soil type in and of itself is not indicative of higher potential VI.	For the Prioritization Scheme, ATSDR is assuming a worst-case scenario; that assumption is that the soils are permeable and there is potential VI risk. Note, when ATSDR runs the J&E model, the agency will use a series of site-specific building, soil, and groundwater characteristics (see Section 3.3.1)

	An additional tool that might be used to improve confidence or adjust the overall potential VI risk of certain areas would be tree sampling for VOCs. There is a body of knowledge supporting the fact that contaminant concentrations in tree-core samples provide quasi-quantitative, multi-phase information from the shallow subsurface. Ideally this could be used in determining the areas of high/medium/low risk or used to add confidence to risk determinations posterior. Because sample collection is typically about 5 minutes per tree, large areas can also be covered in a relatively short period of time. The USEPA also has endorsed this method for characterization of subsurface volatile organic compounds. Vroblesky DA, 2008, User's Guide to the Collection and Analysis of Tree Cores to Assess the Distribution of Subsurface Volatile Organic Compounds: U.S. Geological Survey Scientific Investigations Report 2008-5088, 59 p. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001FRJ.TXT Wilson, J.L., Samaranayake, V.A., Limmer, M.A., Burken, J.G. 2018. Phytoforensics: trees as bioindicators of potential indoor exposure via vapor intrusion. PLoS ONE, v. 13, no. 2, e0193247. DOI: 10.1371/journal.pone.0193247. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0193247. Wilson, J.L., Limmer, M.A., Samaranayake, V.A., Burken, J.G., 2017, Directional Tree Sampling to Locate Soil and Soil-Gas Plumes with Applications in Vapor Intrusion Assessment: Environmental Science and Technology, v. 51, no. 24, p. 14055-14064. DOI:10.1021/acs.est.7b03466. http://pubs.acs.org/doi/10.1021/acs.est.7b03466. Wilson, J.L., Limmer, M.A., Samaranayake, V.A., Schumacher, J.G., Burken, J.G., 2017, Tree Sampling as a Method to Assess Vapor Intrusion Potential at a Site Characterized by VOC-Contaminated Groundwater and Soil: Environmental Science and Technology, v. 51, no. 18, p. 10369-10378. DOI: 10.1021/acs.est.7b02667. http://pubs.acs.org/doi/10.1021/acs.est.7b02667 Wilson, J.L., 2017, Phytoforensics—Using trees to find contamination: U.S. Geological Survey Fact Sheet 2017–3076, 2 p., https://doi.org/10.3133/fs20173076.	ATSDR appreciates Reviewer 1 sharing this additional tool for characterizing VI risk. However, for its VI PHA, ATSDR is evaluating currently available information and data. There are no tree sampling data currently available for MCB Camp Lejeune.

Reviewer	Reviewer Comment	ATSDR Response
2	Yes.	Thank you for the confirmation.
3	The Prioritization scheme does appear to focus on buildings with greatest potential risk with regards to factors generally considered. However, the relatively large number of factors and ranking scheme would appear to dilute the key factor, which is considered to be the predicted average or reasonable maximal exposure concentration to which receptors could be exposed to. Certain factors such as frequency that indoor air measurements are made or distance criteria being met are less important than the receptor concentration.	As stated in Section 3.1.6, ATSDR will perform sensitivity analyses. The main goal of sensitivity analyses is to gain insight into which assumptions are critical. The process involves various ways of changing input values of the computer application to see the effect on the output value. ATSDR agrees one key factor in assessing risk is the contaminant concentration (how much) the receptor was potentially exposed to. The agency intends to increase the number of points assigned in Table 7B, Appendix B, Indoor Air Factor Analysis Chart, as part of its sensitivity analyses to ensure we focus on indoor air exposures in areas with likely VI risk.
	The data quantity and quality should be considered as a separate ranking or classification scheme. Buildings with higher uncertainty may be identified as having a higher priority for additional site characterization.	Table 3B, Appendix B, Frequency of Results Factor Analysis Chart, captures the quantity of data available for contaminants on a building-by-building basis. As ATSDR performs its sensitivity analyses, each table within the classification scheme will be reviewed separately to determine how changing the values impacts the results. As stated in Section 3.1.6, ATSDR may modify its analysis so that the agency can focus its investigation on those areas most likely to be at risk currently for VI.

Reviewer	Reviewer Comment	ATSDR Response
	The current Prioritization Scheme is not clearly defined as to what the purpose or objective of the study is. Prioritization is linked to risk but these are two different concepts. Buildings with higher risk could be prioritized for additional actions. The criteria for risk and prioritization are not well defined, i.e., what are risk thresholds where further actions will be taken, and what will those actions be?	The purpose or objective of the Prioritization scheme is stated in Section 3.1, "ATSDR developed a site-specific Prioritization Scheme that accounts for various VI factors to assist the agency in focusing its evaluation on areas of the base of greatest concern for potential VI impacts. Given the size of the base, it is not feasible for ATSDR to perform separate VI evaluations on each of the approximately 14,000 buildings." Based on the Prioritization Scheme results and ATSDR's professional judgement, the VI risk for each building will be designated as "high potential VI risk," "medium potential VI risk," "low potential VI risk," "no apparent VI risk," and "unknown VI risk." These categories from the Prioritization Scheme, along with other information reviewed during the Refined Analyses (Section 3.2) will help ATSDR focus on areas of the base with buildings that have the highest potential for VI risk first, working towards areas with buildings having low potential VI risk, thereby addressing as many buildings as feasible. The Prioritization Scheme will not be used to determine where further actions will be taken. Through its public health evaluation (Section 3.3.2), ATSDR will determine the need for additional actions and provide recommendations to protect health.

4	The proposed prioritization scheme (Section 3.1) purports to identify buildings of greatest concern for vapor intrusion on the basis of a scoring system, which may have been invented for this work plan. My reservations about this scoring system include the following: • There is no literature reference or citation indicating that this scoring system has been used elsewhere <u>and</u> <u>shown</u> (e.g., by comparison of aggregate numeric scores to measured exposure estimates) to be able to discriminate vapor intrusion potential appropriately among geographic areas (which may have, for example, different source concentrations of vapors and/or soil types in the vadose zone and/or depth to groundwater). • Several of the factors and criteria relied upon in the scoring system (e.g., frequency of results – Table 3B; coefficient of variation – Table 5B; "no data" = zero points – Table 5B; time period during which maximum concentrations occurred – Table 4B) do not obviously have direct predictive value regarding <u>magnitude</u> of time-averaged exposure at a given location. ("Frequency of results", "coefficient of variation", and "no data" would appear to be pertinent, however, to an evaluation of <u>confidence</u> in the characterization of local site conditions.) • Even where the location-specific factors considered in the scoring system (e.g., magnitude of exceedance of a risk-based comparison value – Table 5B) are pertinent to predicting the magnitude of vapor intrusion exposures in a specific, co-located building, no explanation or rationale is offered to demonstrate that the point assignment to the individual factor and/or weighting of points along with all other proposed factors will yield results that correlate with magnitude of exposure for any site-related chemical of concern. • No scheme has been identified or explained that would inform assignment of buildings or areas to "high potential VI risk", "medium potential VI risk", and "no apparent VI risk" categories based upon the scoring system (e.g., no proposed score cut-offs for each category, no proposed weighting of each distinct "factor analysis"). For this reason, it is unclear <u>how</u> "ATSDR will consider the scores" or <u>how</u> the "ATSDR's Prioritization Scheme will assist the agency in designating" each building into an appropriate category. Unless the scores can be and are translated into numeric estimates of exposure or risk, the prioritization scheme could become largely subjective.	ATSDR's responses to Reviewer 4's bullets are as follows: • As stated in Section 3.1, "ATSDR *developed* a site-specific Prioritization Scheme that accounts…" There is no citation for the Prioritization Scheme because the agency used its knowledge of the various lines of evidence for VI evaluations and incorporated them to the best of our ability into this site-specific scheme. Note, the Area Investigation (Section 3.2) and Data Evaluation (Section 3.3) incorporate additional lines of evidence not included in the Prioritization Scheme including depth to ground water and soil type. • Correct, the Prioritization Scheme takes many factors into account, not just the direct predictive value regarding the magnitude of time-averaged exposure at a given location. • The purpose of the Prioritization Scheme is not to yield results that correlate with magnitude of exposure for any site-related chemical of concern. The objective is to help ATSDR focus its evaluation on buildings with the highest VI potential. Toward that end, the agency will perform sensitivity analyses, which include changing the point assignments for individual factors, to gain insight into which assumptions are critical and which may need modification to ensure we focus on areas with likely VI risk. • ATSDR will use technical expertise and professional judgement to evaluate the contaminant scores (compiled as *numerical scores* from Tables 3B–7B, Appendix B) and building factors (compiled as *text* from Table 2B, Appendix B) when determining each building's placement in one of the VI risk categories. ATSDR acknowledges that the final VI risk category assigned to each building may be somewhat subjective; however, the use of the numerical and text factors compiled in table 8B will ensure that these risk categories are assigned in a systematic manner. Further, to ensure the Prioritization Scheme helps the agency focus its evaluation, ATSDR will perform sensitivity analyses. Based on the results of the sensitivity analyses, ATSDR may modify its analysis so that the agency can focus its investigation on those areas most likely to be at risk currently for VI.

Reviewer	Reviewer Comment	ATSDR Response
	By contrast, mathematical models of soil gas intrusion represent an alternative tool (to the proposed scoring system), which could facilitate estimation of the magnitude of vapor intrusion exposures in each area of interest[30]. With such estimates, it should be possible to inform and identify an objective scheme for ranking geographic areas (and specific buildings, if desired) for vapor intrusion potential. Johnson and Ettinger ("J&E") published a one-dimensional model of soil gas intrusion in 1991[31], which could be used in such an approach. Nevertheless, the work plan states, without explanation or justification, that "ATSDR will not run the J&E model as part of the screening approach". The work plan notes that CH2M, on the other hand, "conducted a risk evaluation to determine which buildings had the greatest potential" for vapor intrusion, which included "running the J&E model."	As stated in the work plan in Section 3, "ATSDR will not run the J&E model as part of the *screening approach*" [italic emphasis added]. Although the J&E model could potentially assist in determining VI potential in buildings throughout the base, there are too many buildings for ATSDR to model each one and be timely in our work. The Prioritization Scheme, which incorporates numerous lines of evidence on a building-specific level through use of the site's VI database, was developed to help the agency focus its evaluation. Although the agency will use the Prioritization Scheme and not the J&E approach during screening, ATSDR will use the J&E model to estimate reasonable ranges of attenuation factors based on a series of site-specific scenarios (as part of our estimation of past indoor air concentrations in Section 3.3.1.)
5	The proposed Prioritization Scheme captures several factors that may affect the potential significance of vapor intrusion for a specific building. However, it may not be appropriate to use a simple summation of numerical scores to prioritize the buildings. I appreciate that the work plan appropriately states that the prioritization framework will be reviewed and may be updated following the initial scoring. This may be the key to developing a useful prioritization scheme. However, the authors may want to consider the following thoughts when finalizing the work plan:	Thank you for your comment.
	<u>Reconsider prioritizing a building based on the sum of all analytes reviewed</u>. Should a building with substantial exceedances VICVs (or CVs) for multiple chemicals have a higher priority than a building with a substantial exceedance for 1 chemical? It may be better to use the maximum score value by chemical rather than summing them up.	Table 8B, Appendix B, provides on a building-by-building basis both individual contaminant scores (see column labeled "Overall Points") as well as the total score of all contaminants (see column labeled "Total Factor Analysis Results"). ATSDR will consider all scores (i.e., both individual contaminant scores and total scores of all contaminants), along with the text in the first row of Table 8B, Appendix B, to determine the VI risk category of each building.

[30] Depending upon the degree of resolution sought in the identification of "high VI risk" versus "low VI risk" versus "no VI risk" <u>areas</u>, the modeling could <u>initially</u> consider a standard, generic building for each geographic area and consider a subset of chemicals of concern (e.g., TCE, which is said to be a primary and prevalent contaminant in shallow groundwater), instead of considering each building of interest and each contaminant of interest. Alternatively, if desired, a mathematical model of soil gas intrusion could facilitate systematic estimation of the magnitude of vapor intrusion for each building of interest, for each time-period of interest, and for each contaminant of interest.

[31] Johnson, P.C. and R.A. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors into buildings. *Environmental Science & Technology* 25:1445-1452.

Reviewer	Reviewer Comment	ATSDR Response
	The proposed prioritization scheme does not adequately weigh the different lines of evidence (e.g., groundwater data versus soil gas and/or indoor air data). For example, compare the two hypothetical cases: • Building A has nearby shallow groundwater data that shows high potential for vapor intrusion (e.g., Table 5B Row 2 = 2; Row 4 = 2; and Row 5 = 2; for total of 6), but indoor air data show a low potential for vapor intrusion (e.g., Table 7B Row 1 = -1; Row 2 = ?? [is there supposed be something here for no exceedances?], Row 3 = 0; Row 4 = -1; for a total of -2). • Building B has nearby shallow groundwater that shows a low potential for vapor intrusion (e.g., Table 5B Row 2 = 1; Row 4 = 0; and Row 5 = 0; for total of 1), but indoor air data show a high potential for vapor intrusion (e.g., Table 7B Row 1 = 1; Row 2 = 0; Row 3 = 1; Row 4 = 1; for a total of 3). Both of these examples have a total score of 4, but I believe that Building B (with indoor air concentrations exceeding the CV) would have a higher priority. It is possible that a simple additive prioritization score is not sufficient. Consider providing weighting factors to different lines of evidence in the score. It may also be helpful to adjust the scores so a wider range of final results will be identified. This may be best assessed after completing the sensitivity analysis described in Section 3.1.6.	ATSDR agrees that adjusting the point values in the factor analysis tables might be needed to weigh the different lines of evidence. As part of its sensitivity analyses, ATSDR plans to change the points assigned in the various factor analysis tables to see the effect on the output values (see Section 3.1.6, main bullet 3). In response to this concern, ATSDR added sub-bullets to main bullet 3 in the text to clarify: • Increasing the point values in Tables 5B, 6B, and 7B (e.g., from 2 to 4 and 1 to 2 for all three tables) • Increasing the point values in one table at a time (e.g., from 2 to 4 and 1 to 2 in only Table 7B) • Increasing the point values of specific rows in Tables 5B, 6B, and 7B (e.g., from 2 to 4 and 1 to 2 for just the "Magnitude of exceedance" row in these tables). Based on the results of the sensitivity analyses, ATSDR may modify its analysis so that the agency can focus its investigation on those areas most likely to be at risk currently for VI. With regard to Reviewer 5's question "Row 2 = ?? [is there supposed to be something here for no exceedances?]", ATSDR updated the text in Tables 5B, 6B, and 7B for the "Magnitude of exceedance" rows to state, "Choose for all other situations" in the zero point column.
	Consideration of both measured and modeled groundwater data. It seems that consideration of both measured and modeled groundwater data in Table 5B doubles the potential impact of the groundwater assessment on the building prioritization. How well do the groundwater data match the measured data? Would it be appropriate to use just one of these data sets (maybe the more conservative of the two results (but see my comment below)? If the differences between measured and modeled data are significant, maybe it is not appropriate to use the modeled data.	In Section 3.1.2, added a bullet to the specific tasks stating we would "…compare simulated shallow groundwater results for Model Layer 1 with measured shallow groundwater results for similar locations and time frames to determine how well the simulated concentrations are similar to the measured concentrations..." ATSDR agrees if the differences between the measured and modeled data are significant, it would not be appropriate to use the modeled data. As stated in Section 3.1.6 (Sensitivity Analyses), main bullet 5, ATSDR already plans to run the computer application with only measured data, i.e., not include shallow groundwater simulated data to observe the effect on the computer application output results.

Reviewer	Reviewer Comment	ATSDR Response
	Use of groundwater contours. It is not clear to me if "measured" concentrations include estimated values based on groundwater concentration contours. These may be suitable for the prioritization scheme.	For the Prioritization Scheme, ATSDR does not intend to use groundwater concentration contours. ATSDR will use available measured and simulated shallow groundwater data within 100 ft of a building for screening purposes on a building-by-building basis for each contaminant.
6	The prioritization scheme appears to be appropriate to identify buildings of concern for those areas of concern identified by ATSDR as having the greatest potential vapor intrusion risk. Information is not provided on how this initial cut was determined and therefore, I cannot comment on this step of the analysis. The prioritization scheme appears to follow a 6-step process: (1) Identify and compile existing groundwater, soil vapor, and indoor air data; (2) Compile simulated groundwater data; (3) Collect building information including whether the building is occupied, or located within 100 feet of a known groundwater plume or free product; (4) Identify relevant media- and chemical-specific screening values (i.e., VICVs) to allow for plume mapping; (5) Screen data on a building by building basis; and (6) Conduct sensitivity analysis The approach uses a variety of methods to evaluate buildings of concern including starting with buildings and confirming if they are within 100 feet of any elevated groundwater detections. In addition, the prioritization also maps the shallow groundwater plumes and then identifies any buildings within 100 feet (Section 3.1.4). While the overall approach appears to be valid, the specific rankings of the factor analysis charts will be critical to determining which buildings are determined to be high, medium, or low priority. My specific comments are as follows:	Thank you for your comment.

Reviewer	Reviewer Comment	ATSDR Response
	The Work Plan does not discuss how the final factor analysis will be weighted or ranked to determine a building status. In other words, what overall point number would determine a high ranking versus a medium ranking. To avoid bias in this process, ATSDR should determine the criteria and numbers to be used in advance of any ranking. In addition, ATSDR should consider ranking or weighting some of the criteria considered. For example, the magnitude of the groundwater exceedance (Table 5B) may be a more important criteria than the number of samples available. As currently structured, this variable is only one item in a much larger table and the potential importance of this value is likely to be lost in the number of criteria summed together.	ATSDR will use technical expertise and professional judgement to evaluate the contaminant scores (compiled as *numerical scores* from Tables 3B–7B, Appendix B) and building factors (compiled as *text* from Table 2B, Appendix B) when determining each building's placement in one of the VI risk categories. Therefore, ATSDR cannot determine an overall point number in advance for placing buildings into VI risk categories because the placement will be determined by both *numerical scores* and *text*. Further, the numerical scores might change based on the sensitivity analyses ATSDR conducts. ATSDR already plans to change the points assigned in the various factor analysis tables to see the effect on the output values (see Section 3.1.6, main bullet 3). For clarity, ATSDR added sub-bullets to main bullet 3 to show examples of some of the factors the agency intends to change. For example, the agency added the sub-bullet "increasing the point values of specific rows in Tables 5B, 6B, and 7B (e.g., from 2 to 4 and 1 to 2 for just the "Magnitude of exceedance" row in these tables)."
	In addition to the lack of ranking, the criteria approach does not seem to allow for the evaluation of variables that are inconsistent or could indicate another issue. For example, if chemicals are present in groundwater and indoor air, but not soil vapor, would this be flagged in the database and how would that information be evaluated to understand why the data are inconsistent. It does appear that this concern will be addressed in Section 3.2.2; however, it is unclear how that may change/influence the prioritization scheme.	For Section 3.1, a computer application will be developed to compile data from the VI database to complete the Prioritization Scheme. Table 8B, Appendix B, will display the results on a contaminant-by-contaminant basis for each building; therefore, ATSDR will know whether contaminants are present in groundwater and indoor air (i.e., noted by the points the columns for the results of these media), but not soil gas (i.e., noted by the lack of points in the column for the soil gas medium). Although the computer application will not flag these results, review of the output will show potential inconsistencies that ATSDR will consider when placing a building within one of the VI risk categories. Note that the Prioritization Scheme (Section 3.1) is only the first step ATSDR will take to focus its evaluation on buildings of greatest concern for potential VI impacts. In Section 3.2, ATSDR will compile additional sources of information that might aid in focusing ATSDR's VI evaluation as well as assist in determining why some of the data appear inconsistent.

Reviewer	Reviewer Comment	ATSDR Response
	Section 3.1.4 discusses the use of Comparison Values (CVs) for indoor air and then presents the calculation of groundwater and soil vapor CVs from the initial risk based values. The method for calculating the groundwater and soil vapor CVs is consistent with standard USEPA approaches; however, the initial air CVs are not presented anywhere in the document, nor is a clear reference provided that presents the values or where they may be sourced. The toxicity of each of the chemicals evaluated is a critical piece of the evaluation and should be much more clearly documented in the work plan. It is unclear if these values will be similar to the USEPA Regional Screening Levels or if ATSDR is using its Minimum Risk Levels (MRLs). Overall, however, I strongly agree with ATSDR's categorization of most toxicity values developed by regulatory agencies. The many uncertainty factors added to numbers to increase their health protectiveness ensures that these values will not underestimate and most likely overestimate potential health effects.	ATSDR and USEPA have residential health-based air CVs [ATSDR 2018, USEPA 2017], which will be used to screen contaminant data for the Prioritization Scheme. Reference citations for these CVs were added to the work plan. In response to this comment and other similar comments, ATSDR also added Tables 9B and 10B, Appendix B, to the work plan to provide the air CVs as well as the calculated groundwater and soil gas VICVs.
	In Section 3.1.5, ATSDR discusses adjusting the commercial indoor air levels for comparison to the CVs. I initially did not understand this approach and I think it will be confusing to the public. I would instead recommend adjusting the CVs to develop a commercial CV that can be compared to data from commercial buildings instead of the approach being taken by ATSDR.	ATSDR prefers to adjust the exposure point concentration, not the CV, for screening purposes; therefore, no change was made to the work plan in response to this comment.
	Section 3.1.5 indicates that the Agency will compare maximum contaminant levels to a short term CV and 95% UCLs to a long term CV. However, the Agency also indicates that sufficient data are not likely to calculate 95% UCLs in all cases. Under these conditions, will the maximum value also be compared to the long term CV? If so, this should be noted in the text.	Correct, when sufficient data are not available to calculate 95% UCLs, the maximum value will be compared to the long-term CV. ATSDR added a footnote to Section 3.1.5, specific tasks main bullet 5, sub-bullet 1, sub-sub-bullet 2, to clarify that when ATSDR was not able to calculate a 95% UCL for the measured results, the contaminant's maximum value will be used in place of the 95% UCL value for long-term screening.
	Section 3.1.5 also states that ATSDR may use structure activity relationships to develop toxicity values for approximately 30 chemicals. While I have no objection to this approach, I would strongly urge ATSDR not to make any regulatory or final decisions based on these data. Using such data adds another layer of uncertainty into the process that may just serve to confuse the public.	For those 30 contaminants, the agency is only considering using software that assists with finding structural similarities between contaminants. Other information considered includes how often the contaminant was detected in each environmental media, the range of contaminant concentrations in each media, and the contaminant's properties such as Henry's law constant to determine volatility of each contaminant. The agency will also check whether there are available comparison values from other entities such as state agencies.

	Finally, given the massive amount of data that will be used in the prioritization scheme, ATSDR should develop and identify the methods that will be used to conduct a quality control (QC) evaluation. Some level of QC should be conducted to confirm the data inputs, outputs, and analysis.	To QC data extracted from the source documents, ATSDR performed the following steps: 1. Each document identified within a keyword search was examined by at least two people. The first person reviewed the entire document and extracted relevant sampling data into ATSDR's standardized data extraction template in Excel. Once they finished, a second person would QC their work by reviewing a certain percentage of the data they extracted for accuracy. When the first person was someone newly assigned to the project, the second person would review 100% of the data they extracted from each document. Once the first person's understanding of the data extraction procedures had been confirmed, the second person would review 5% of the data (every 20th row in the data extraction template). The second person would also use filter tools in Excel to search for errors in the extracted data, and would review the source document to confirm that all relevant data were extracted. If the second person identified major errors in the data file, they would return it to the first person for correction and would review it again once corrections were made. 2. Once all relevant data had been extracted from the documents identified in the keyword searches, ATSDR performed an additional QC review on the entire VI database. ATSDR reviewed the unique entries in each field of the database and searched for any data that appeared incorrect or out of place (e.g., text entries in numeric fields, easting/northing coordinates in the latitude/longitude fields, typographic errors, etc.). Corrections were made to the original data files and to the full database as errors were identified. 3. Once the initial QC of the entire database was complete, ATSDR standardized the data in the database to account for differences in the ways that data were defined and presented in the source documents. This standardization step involved a thorough review of the contents of all key fields in the database, which in some cases identified additional errors. Any errors identified during the standardization step were corrected in the full VI database. 4. After standardization was complete, ATSDR performed a final QC review of the standardized database, again by searching for data that appeared incorrect or out of place in each field within the database.

Reviewer	Reviewer Comment	ATSDR Response
		Steps #1–4 are completed. Following the development of a computer application to compile data from the VI database to complete the Prioritization Scheme, sensitivity analyses will ensure that the agency can focus its investigation on those areas most likely to be at risk currently for VI. The process involves various ways of changing application input values to see the effect on the output value. Output results will also be compared with datasets of known and suspected shallow groundwater plumes for the base and three free product areas within the HPIA. Comparison with these datasets will ensure that the computer application adequately identifies areas of contamination and will allow for a more objective analysis of the validity of each set of parameters used in the sensitivity analyses. Because CH2M used a different approach to determine which buildings had the greatest potential for VI, ATSDR will also compare the buildings identified by its Prioritization Scheme to the building list developed by CH2M to determine whether CH2M identified any buildings that ATSDR did not. This comparison will be an additional check to ensure the computer application identifies building of potential concern for VI.
	With respect to Section 3.2.2 Area Investigation, I believe that this is definitely a useful endeavor. Visually mapping data and other information can identify trends or other inconsistencies in the data (i.e., present in indoor air but not other media). ATSDR should proceed with the area investigation, but sufficient information is not currently provided to allow for a detailed review of the process and data analysis steps that will be taken to conduct this part of the analysis.	Thank you for your comment. In Section 3.2.2 (Area Investigation), the work plan describes how ATSDR will use exploratory data analysis to get a “feel” for the data set. The agency only generally described GIS mapping to visualize areas of the base in the work plan because exploratory data analysis is not a set technique or procedure.
4. Is the method to estimate historical (i.e., past) exposures to indoor air appropriate (Section 3.3.1)?		
1	I found the approach outlined in the Work Plan to be appropriate in estimating the potential indoor-air risk from VI in the presence of mitigation systems. My previous comment on attenuation factors from the USEPA apply to Section 3.3.1 as well and may need to be increased in areas where groundwater or source areas are less than 5 feet from ground surface.	ATSDR agrees that the attenuation factors may need to vary when depths to groundwater are less than 5 ft, and for those areas, the agency will assume no attenuation is occurring. The agency added a bullet to Section 3.3.1 stating, • “For buildings with an average depth to groundwater of <5 ft, change the groundwater attenuation factors for the above estimated indoor air contaminant calculations to assume no attenuation is occurring (i.e., attenuation factor equals 1).”

Reviewer	Reviewer Comment	ATSDR Response
2	Yes, with the caveat that inhalation exposures from the historic groundwater/ drinking water supply should be combined with the inhalation exposure from vapor intrusion.	ATSDR will qualitatively acknowledge contributions from inhalation exposure from past groundwater/drinking water supply. Because calculating historical indoor air estimates for VI will already introduce a large degree of uncertainty, the agency does not expect to combine past estimated VI inhalation exposures with the estimated inhalation exposures from groundwater/drinking water presented in the January 20, 2017 Public Health Assessment.
3	Re-constructing past exposures would appear to be a daunting task as it is anticipated there will be significant uncertainty in estimated historical groundwater concentrations and modeling of indoor vapor concentrations particularly for buildings including those that are demolished. Section 3.1.1 is mostly limited to describing how data will be obtained and does not describe the modeling process to predict indoor air concentrations from groundwater or soil gas data. A different section of the work plan does indicate an attenuation factor of 0.0001 will be used for industrial buildings and 0.03 for residential buildings. Consideration could be given to deriving site specific factors. The attenuation factor chosen will also depend on the purpose of the estimation process, i.e., to reconstruct a best estimate of the possible exposure or reasonable maximal exposure concentration (likely the later?). The statistical basis for the approach should be more clearly described.	Section 3.1.1 describes the measured data that will be used in the Prioritization Scheme, which is a computer application not a model. The scheme is part of the screening process and will help ATSDR focus its evaluation on areas of the base of greatest concern for potential VI impacts. Section 3.3.1 (Estimate Historical Indoor Air Exposures) is a part of the data evaluation section. As stated in this section of the work plan, • ATSDR will use the USEPA general groundwater AF_{USEPA} (0.001) for estimating upper bounds air concentrations for buildings designated as school, residence, health care, or unknown. • ATSDR will use two different non-residential groundwater AFs for workplace, warehouse, and storage buildings. One non-residential AF is the AF_{NESDI} of 0.0001, which was developed for industrial buildings on a variety of bases around the country. The other non-residential AF will be calculated for a few buildings on the base where building-specific characteristics are known. • ATSDR will use the J&E model to estimate reasonable ranges of AFs based on a series of site-specific scenarios. The ranges will be used to explore the upper and lower bounds of vapor intrusion using a series of site-specific building, soil, and groundwater characteristics.

Reviewer	Reviewer Comment	ATSDR Response
4	Use of generic groundwater-to-air attenuation factors (AF_{gwv}) to extrapolate indoor air concentrations from chemical concentrations in shallow groundwater represents a blunt "modeling" approach for exposure assessment. Whereas the USEPA's generic AF_{gwv} value for residential buildings was derived to support risk-based screening "to identify sites or buildings unlikely to pose a health concern through the vapor intrusion pathway", it does not take into account soil conditions or depth to groundwater, to mention just two of the relevant location-specific factors that may vary across the "area(s) of potential vapor intrusion" at Camp Lejeune Base and can influence vapor intrusion potential for residential buildings. Likewise, the two options proposed for representing attenuation in non-residential buildings (AF_{NESDI} and non-res AF_{gw})[32] do not take into account the relevant location-specific factors that may vary across the "area(s) of potential vapor intrusion" at Camp Lejeune Base and can influence vapor intrusion potential for non-residential buildings.	To account for relevant location-specific factors, ATSDR will use the J&E model to estimate reasonable ranges of AFs based on a series of site-specific scenarios. • The ranges will be used to explore the upper and lower bounds of vapor intrusion using a series of location-specific building, soil, and groundwater characteristics. • ATSDR will also compare the AF ranges from the J&E model to the USEPA, NESDI, and calculated AFs that will be used to estimate past indoor air concentrations.

[32] Although these proposed options for representing vapor attenuation for non-residential buildings vary only by a factor of two-fold (0.0001 versus 0.0002), the variability and uncertainty in this factor, on a building- and climate-specific basis, are expected to be significantly greater than two-fold.

Reviewer	Reviewer Comment	ATSDR Response
	Furthermore, in choosing/using values of attenuation that are reasonably expected to be "conservative" (i.e., tend to under-estimate attenuation in concentration and over-estimate vapor concentration in indoor air) for each building category, the proposed method is likely to over-estimate vapor intrusion exposures, even when central tendency values are chosen/used for the groundwater (vapor source) concentration. When high-end (e.g., maximum or 95%UCL) values are used to represent the groundwater (vapor source) concentration, as is proposed in the work plan, the result may be an over-estimated exposure concentration that is unlikely ever to have been experienced.[33]	ATSDR agrees the proposed method to estimate past indoor air exposures might over-estimate vapor intrusion exposures. The confidence the agency places on its indoor air estimates will depend on how well the estimated indoor air concentrations are similar to the actual indoor air measurements when measured indoor air data are available. At the building level, ATSDR will qualitatively acknowledge contributions from inhalation exposure from past groundwater/drinking water supply via showering, dish washing, etc. as well as other potential indoor and outdoor sources.
	The work plan proposes to estimate a range of building-specific vapor concentrations in indoor air by considering a variety of concentration statistics, when available, to characterize shallow groundwater quality (i.e., the vapor source), along with the afore-mentioned generic attenuation factors. If the goal of these multiple calculations is to characterize uncertainty in the historic exposure estimates within each time period, ATSDR might want to consider alternative approaches that examine influential variables that are most uncertain.[34]	While attempting to gain as accurate as possible estimations on "true conditions" using statistics, such as with the groundwater data, ATSDR will also examine other influential variables, such as fate and transport parameters.

[33] Comparing building-specific measurements to estimated vapor concentrations indoors for a few buildings could support some insights into whether and by how much the proposed approach over-estimates exposure concentration. Such "ground-truthing" {my term}, in advance of finalizing the work plan, could be worthwhile for purposes of providing confidence that the proposed approach ultimately will yield practically useful results, if and when applied more broadly – or the results might support pursuing an alternative approach. [The work plan proposes (page 20) to compare building-specific measurements of vapor concentration in indoor air to exposure estimates obtained using its proposed (generic AF-based) approach, which is a generally recommended practice. ATSDR might want to consider doing so as part of its work plan development, however, rather than only as part of work plan execution.] There is, however, an important caveat associated with relying upon building-specific measurements of vapor concentration in indoor air, which may be difficult to overcome at the Base. Specifically, in buildings that were serviced by drinking water distribution systems that delivered contaminated groundwater, historic vapor concentrations of site-related contaminants are likely to be elevated in indoor air due to volatilization from drinking water, independent of any contribution from soil gas intrusion. For this option for "ground-truthing" to be reliable, it will be important to identify indoor air measurements: (i) from buildings that did not receive contaminated drinking water for the time period of interest; and (ii) that can be shown to be attributable to soil gas intrusion.

[34] Concentrations of vapor-forming chemicals in groundwater samples can routinely be measured with confidence about their accuracy.

Reviewer	Reviewer Comment	ATSDR Response
	One alternative approach to estimating historic (and current) exposures that merits consideration is to employ the Johnson and Ettinger ("J&E") model of soil gas intrusion, and take into account location-specific information[35] about soil type and depth to groundwater for the time period of interest.[36] A range of values of the ratio of soil gas entry rate (Q_{soil}) to ambient air infiltration rate (Q_{bldg})[37] could be considered to help characterize uncertainty in building conditions and characteristics (e.g., Q_{soil}/Q_{bldg} = 0.03 versus 0.003 in the case of a residential building). Unlike measurements of vapor concentrations in indoor air, modeling estimates would not be confounded by the presence of vapors from sources other than soil gas intrusion.	ATSDR will consider soil type, groundwater depth, and a range of values of the ratio of soil gas entry rate (Q_{soil}) and ambient air infiltration rate (Q_{bldg}) in the evaluation. Note also that a Q_{soil}/Q_{bldg} default value (0.003) and range (0.0001 to 0.05) for residential and commercial buildings is provided in the J&E model.
	Johnston & Gibson (2011)[38] used the J&E model to simulate/predict vapor intrusion exposures in a community overlying a plume of contaminated groundwater. Owing to localized differences in expected soil type, they found that predicted indoor air concentrations did not strictly conform to concentrations of tetrachloroethylene and trichloroethylene in the underlying plume,[39] thereby demonstrating the utility of a predictive tool that relies upon a wide array of critical inputs.	ATSDR will attempt to incorporate geospatial information on soil type, to the resolution available.

[35] I infer that relevant information about soil type(s) and depth to groundwater, among other relevant factors, has already been compiled and validated for some geographic areas to support the "groundwater-flow and contaminant fate and transport" modeling, as part of ATSDR's public health assessment of drinking water consumption at the Base, or, as part of CH2M's remedial investigation, to support its modeling of soil gas intrusion.

[36] The work plan proposes (page 20) to implement the J&E model, but apparently only for purposes of "ground-truthing" {my term} the generic attenuation factors. See comment #5.

[37] See, for example: Johnson, P.C. 2005. Identification of application-specific critical inputs for the 1991 Johnson and Ettinger vapor intrusion algorithm. *Groundwater Monitoring & Remediation* 25(1): 63-78.

[38] Johnston, J. E., & Gibson, J. M. (2011). Probabilistic approach to estimating indoor air concentrations of chlorinated volatile organic compounds from contaminated groundwater: A case study in San Antonio, Texas. *Environmental Science and Technology 45(3)*: 1007-1013.

[39] Whereas highest contaminant concentrations in groundwater were found closest to the subject site, where chemicals were released to the environment, the predicted vapor concentrations in indoor level were also high approximately two miles from the site in an area believed to have sandy soil, rather than clay-rich soils common near the site and in the rest of the community (see, for example, Figure1c therein). In this case, the modeling relied upon soil texture classifications for the study area from the U.S. Department of Agriculture.

Reviewer	Reviewer Comment	ATSDR Response
5	It is hard to judge the potential error estimating historical indoor air concentrations, because I do not know the error/uncertainty with the historical groundwater data. My initial thought was whether this step was a necessary objective. If this is an important evaluation for ATSDR, I don't have a recommendation for a better way to estimate past exposures. However, please note the following items: • There is an error in the equations used to estimate indoor air concentrations in this section. The IA concentrations = AF x HLC x GW concentrations (where HLC is the dimensionless form of the Henry's law coefficient) • There may be cases where the exposure duration/frequency for historical receptors is known and assumptions different from default values may be used in calculating historical CVs.	Based on concerns expressed to the agency, ATSDR finds it necessary to try to put past VI risk into perspective for the MCB Camp Lejeune community. With regard to each bullet: • Thank you for catching this error; the work plan was updated with the correct equations. • ATSDR does not modify its CVs, but instead modifies the exposure point concentration to reflect the correct duration/frequency, when needed.
6	In the absence of building-specific indoor air data, I believe it is appropriate to estimate indoor air concentrations using an attenuation factor (AF). The USEPA AF of 0.001 was calculated for residential homes. This value should be used, but is should be noted that it may be too conservative (assume too much migration of vapors) even for residential homes. Using data on commercial buildings or site-specific data for non-residential buildings is appropriate. I also agree with the calculation of indoor air concentrations over a range of groundwater concentrations (i.e., max, 95% UCL, and min). This helps place bounds on the potential indoor air concentrations that could have been present historically.	Thank you for your comment.
	My two comments on the current approach are: (1) The initial step where the data are evaluated to determine if they are representative over space and time is of potential concern. Since this will be based on professional judgement it is important that any decisions are clearly documented. It may also be very helpful to have a single person conduct the analysis to ensure consistency in the process.	ATSDR plans to document its decisions regarding whether the data were found to be representative over space and time. The lead health assessor for the VI PHA will be involved in all steps of the decisions process, which ensures consistency in the process.

Reviewer	Reviewer Comment	ATSDR Response
	(2) It appears that many buildings may not be evaluated if sufficient samples were not collected to calculate a 95% UCL. It is unclear how many building evaluations this will eliminate, but ATSDR should consider using another statistic for those buildings with slightly less data. This might be a good place to consider using the sensitivity analysis (for example, use maximum values and see how many more buildings could be evaluated).	Correct, it is unclear how many buildings will have sufficient samples for an evaluation of past VI risk. Calculating historical indoor air estimates will introduce a large degree of uncertainty. Buildings with insufficient shallow groundwater data representative over space and time cannot be evaluated; that is, ATSDR can only estimate historical indoor air levels when sufficient shallow groundwater data exist (see Section 3.3.1). However, when sufficient data for a building are not available, ATSDR will use maximum contaminant values to represent the 95% UCLs in the Prioritization Scheme (see Section 3.1). ATSDR will also use maximum indoor air contaminant levels to evaluate the public health implication of indoor air exposures (see Section 3.3.2).
5. With regard to determining uncertainty in the estimated (i.e., historical) indoor air concentrations, are the proposed use of Kendall's Tau rank correlation coefficient and the Johnson and Ettinger (J&E) vapor intrusion screening model appropriate (see page 20 of the Work Plan)?		
1	Application of the Johnson-Ettinger model as a tool to develop ranges or distributions of possible attenuation factors is a good approach. Although there are many correct ways to approach using the J&E model to provide an estimate of the range of indoor-air concentrations, I would suggest using a stochastic approach (e.g., Monte Carlo) and incorporating the site-specific knowledge of the uncertainty in each input parameter into ensembles. I agree that the use of the Kendall's Tau rank correlation coefficient is appropriate to compare known and estimated indoor-air concentrations over time and space.	Thank you for your comment. ATSDR does not have the resources to implement a stochastic approach in running the J&E model. A bounding approach that incorporates the site-specific knowledge and uncertainties in the parameters will be used instead.
2	Yes, unless some buildings have specific features which violate the J&E assumptions (i.e. the building is not slab on grade).	ATSDR will be gathering building-specific characteristics related to construction that will indicate whether the building is not on a slab (see Section 3.3.1, specific tasks bullet 2).

Reviewer	Reviewer Comment	ATSDR Response
3	Kendall's Tau will be used to assess how well predicted concentrations match measured concentrations. A comparison of rank such as Kendall's Tau is one method that could be used. It is recommended that regression analysis also be performed. It is indicated that the Johnson and Ettinger model will not be used for prioritization, but a footnote indicates the J&E model will be used. The scope of the J&E modeling is not clear. The Johnson and Ettinger model is considered appropriate to use for screening and prioritization purposes, if conceptual site model is well understood, and appropriate input parameters are used. Key input parameters for Johnson and Ettinger model include the soil moisture content, the soil gas advection rate and building ventilation rate. These parameters are challenging to estimate when performing a large meta-data analysis, and soil type and soil gas advection rate are no mentioned in the report text. It is imperative that input parameters for the modeling be carefully selected based on literature values and professional judgment. Where there are indoor air data available, the model should be calibrated to the extent possible. Probabilistic modeling using the Johnson and Ettinger model could be considered for buildings or areas with sufficiently detailed data on input parameters.	ATSDR will consult USEPA documentation and guidance when using the J&E model to estimate reasonable ranges of vapor intrusion and compare the results to measured indoor air data. Site-specific parameters, such as soil type and building size, will be used when available. ATSDR will use USEPA's default parameters and literature values, when appropriate. ATSDR does not have the capacity to perform probabilistic modeling at this time. Regression analysis is similarly likely beyond the scope of work for the VI PHA evaluation. The intention of the modeling is to provide a line of evidence to support the measured data by calculating reasonable ranges of vapor intrusion and using the comparison as part of an uncertainty analysis.
4	Personally, I do not have sufficient and appropriate experience or expertise regarding Kendall's Tau rank correlation to offer an informed comment on its proposed use in the work plan. For purposes of "ground-truthing" {my term} the generic attenuation factors, ATSDR might want to consider performing the modeling as part of its work plan development to support some insights into whether and by how much the proposed (generic AF) approach over-estimates exposure concentration, rather than only as part of work plan execution.	ATSDR recognizes that the generic attenuation factors are typically upper percentile values intended for use in screening. ATSDR will note this when comparing the different results and measured datasets. Because ATSDR will not know which buildings will be of highest priority for modeling until after the Prioritization Scheme ranking is performed, the J&E modeling cannot be performed at this time.
5	The use of the Kendall Tau rank correlation coefficient to assess the uncertainty in the estimated indoor air concentrations is difficult to assess without a better understanding of the data sets to be compared (e.g., how many samples, varying conditions/input assumptions for the J&E model). At this time, I am not sure the proposed statistic is appropriate.	Because ATSDR is currently developing the computer application for the Prioritization Scheme and has not begun J&E modeling, information about the datasets and model inputs is not yet known. However, the agency will provide this information (e.g., how many samples, varying conditions/input assumptions for the J&E model) in the VI PHA.

Reviewer	Reviewer Comment	ATSDR Response
6	I don't have enough experience with use of Kendall Tau rank correlation coefficient to comment on this aspect of the work. The J&E model may potentially provide some useful information on historical ranges of indoor air concentrations; however, I would rely more heavily on the AF ranges from empirical data; especially if the data are from sites with similar building, soil, and groundwater conditions. The biggest challenge with using the J&E model is the lack of data on air exchange rates. This input is extremely sensitive in the model and can change results by orders of magnitude. Without these data, the reliability of the model may be more uncertain.	ATSDR will consider the empirical data as an important line of evidence that most directly indicates exposures. The use of a range of parameters for the J&E model (such as $Q_{soil}/Q_{building}$) is intended to explore the possible effects of different conditions for idealistic scenarios and see if they are relatable to empirical data. This helps support the development of appropriate conceptual site models. ATSDR agrees with the commenter on these points about the J&E model and empirical data.
6. Is the use of building-specific conceptual models to determine the public health implications of potential current and historical exposures to indoor air contamination that may have resulted from vapor intrusion into buildings on the base appropriate (Section 3.3.2)?		
1	Yes, I found the approach in Section 3.3.2 to be appropriate. As in comments #3 and #4, use of the USEPA attenuation factors for groundwater and soil gas or all samples may not be appropriate in areas where groundwater or sources are less than 5 feet below ground.	Thank you for your comment. ATSDR agrees that the attenuation factors may need to vary when depths to groundwater are less than 5 ft,and for those areas, the agency will assume no attenuation is occurring. The agency added a bullet to Section 3.3.1 stating, • "For buildings with an average depth to groundwater of <5 ft, change the groundwater attenuation factors for the above estimated indoor air contaminant calculations to assume no attenuation is occurring (i.e., attenuation factor equals 1)."
2	At a minimum, whether the foundation is slab on grade, basement, or elevated/crawl space should be considered.	ATSDR will be gathering building-specific characteristics related to construction that will indicate whether the building is slab on grade, basement, or elevated/crawl space (see Section 3.3.1, specific tasks main bullet 2).
3	Development of a building-specific conceptual model is considered appropriate, although subsurface properties of soil moisture must also be considered. With respect to building, the foundation type (e.g., basement, slab at grade) and size is not noted.	Subsurface properties of the soil will be compiled from ATSDR's historical modeling effort and USDA maps. As stated previously, the agency will gather information such as the building foundation type. Size will be estimated from the building footprint (see Section 3.1.3).

Reviewer	Reviewer Comment	ATSDR Response
4	The proposed "building conceptual models" appear to represent summaries of building-specific information that has been or will be compiled, which will be reported in maps and tables that will accompany the results of the risk assessment and related procedures that comprise the public health evaluation. It is not obvious how these "building conceptual models" would be used *per se* by ATSDR's public health staff to determine public health implications. For example, perhaps the information is intended only: (i) to supplement the narrative, building-specific findings about potential for adverse health effects; and (ii) to be used and interpreted by interested readers of the final assessment report, as those readers deem fit.	As stated in Section 3.3.2, ATSDR will conduct a review of the supporting toxicological research to evaluate the potential for site exposures to cause harm. In addition to the toxicity of the contaminant, the human body's response to a contaminant exposure is determined by several additional factors, including the • Concentration (how much) of the chemical the person was potentially exposed to, • Amount of time (how long) the person was potentially exposed, and • Route by which the person was exposed (e.g., breathing the chemical). The building conceptual models will include information about the contaminant concentrations and amount of time the person was potentially exposed. The models will also include building-specific characteristics that will aid ATSDR in determining whether there is potential VI risk. The models will also help guide ATSDR in determining the most appropriate recommendations to protect public health. Effective figures and tables for communicating the results of ATSDR's evaluation will be included in the VI PHA.
	It is also not apparent how ATSDR "will also determine effectiveness of soil vapor mitigation systems installed in buildings on the base". The work plan states only that ATSDR will use "more recent data."	Using more recent data, ATSDR will evaluate the public health implications of current indoor air exposures to occupants in buildings with vapor intrusion mitigations systems. To further explain, the agency added a sub-sub-bullet to Section 3.3.2 of the work plan under specific tasks main bullet 3, sub-bullet 4, "If the agency's evaluation finds indoor air contaminants in a building are below levels expected to harm health, the agency will conclude the system is effective at reducing indoor air contaminant concentrations for that building."
5	Incorporation of building-specific information into the conceptual models is a useful component of the vapor intrusion pathway assessment.	Thank you for your comment.

Reviewer	Reviewer Comment	ATSDR Response
	An additional site-specific consideration (as opposed to a building specific factor) is whether data collected at the site indicates that the generic AFs are appropriate or inappropriate for the public health assessment. For example, if the measured indoor air concentrations are consistently below the estimated values based on soil vapor results and the generic attenuation factor of 0.03, then an alternate attenuation factor should be used to estimate indoor air concentrations for buildings/time periods where indoor air data are not available.	If the measured indoor air concentrations are consistently below the estimated values for buildings with indoor air data, ATSDR will provide in the VI PHA both the original estimated indoor air concentrations based on generic attenuation factors as well as adjusted indoor air concentrations. The adjusted indoor air concentrations will be based on J&E modeling. ATSDR will use the J&E model to estimate reasonable ranges of AFs based on a series of site-specific scenarios. The ranges will be used to explore the upper and lower bounds of vapor intrusion using a series of site-specific building, soil, and groundwater characteristics.
	However, it is unclear exactly how these factors will be considered in the public health assessment. It is possible that some of the factors listed in this section should preclude the comparison of measured indoor air concentrations to CVs.	Some factors (like building foundation) will be gathered later in the investigation for only those buildings with potential VI risk. However, known building-specific factors will be used in all sections of ATSDR's evaluation.
6	In theory, the overall approach to evaluate each building and determine the potential for adverse health effects is appropriate. Because indoor air concentrations (exposure point concentration) is building specific, it is appropriate to evaluate health effects by building. However, the exact method that ATSDR will use to evaluate health effects is not clearly stated. For example, will ATSDR calculate hazard quotients and cancer risks for each building based on the available data? How will the data results be put into context in relation what is known about the toxicity for each of the chemicals of concern.	ATSDR will provide general toxicity information for each contaminant of concern at the beginning of the public health evaluation section of the VI PHA. This toxicity information will include relevant no-observed-adverse-effect-levels (NOAELs), lowest-observed-adverse-effect-level (LOAELs), and cancer effect levels (CELs) in the studies. Later in the public health evaluation section of the VI PHA, building-specific contaminant exposures will be compared to the relevant NOAELs, LOAELs, and CELs via a computer application that will generate Excel output tables. In addition, to help put into context the toxicity information, the agency will provide figures in the VI PHA for some of the buildings evaluated that contain the building-specific contaminant results and the NOAELs, LOAELs, and CELs.
	As noted in Section 3.3.1, ATSDR is calculating a range of historical indoor air concentrations. This information could be used to calculate a range of potential noncancer hazard and cancer risks and be used to put the information into perspective. A similar approach (range of values) could be used for the current indoor air data.	ATSDR agrees providing a range of results can help put the information into perspective, and will incorporate those ranges in the VI PHA figures.
	Finally, I would note that use of literature and toxicological data is often subject to significant controversy (for example, trichloroethylene and 1,4-dioxane). ATSDR may be focused on correctly determining indoor air concentrations for a large number of buildings, but it should not lose sight of the fact that the identification of peer reviewed and accepted toxicology data is also critical to this process and the determination of potential health effects.	ATSDR agrees the identification of peer reviewed and accepted toxicology data is critical to the determination of potential health effects.

Reviewer	Reviewer Comment	ATSDR Response
7. Are there any other comments?		
1	All other comments, including those that are less consequential, have been added as track changed in the word document.	Thank you for the comments and edits. ATSDR has reviewed and incorporated them into the work plan, where appropriate. Please see "Additional Document Comments" later in this table for Reviewer 1's specific comments and ATSDR's responses.
2	No.	No response needed.
3	Please see attached document with embedded comments.	Thank you for the comments and edits. ATSDR has reviewed and incorporated them into the work plan, where appropriate. Please see "Additional Document Comments" later in this table for Reviewer 3's specific comments and ATSDR's responses.
4	ATSDR appears prepared to devote a substantial amount of resources, including human effort, towards obtaining and organizing a substantial volume of information, which is likely to be appreciated by the community and other stakeholders. The work plan appears to indicate (see Section 3.3, page 17) that health risks and potential health effects will be characterized for "as many buildings as feasible", after: (i) the proposed "Prioritization Scheme" (see Section 3.1) is implemented, which entails a substantial effort to evaluate and incorporate data about past conditions; (ii) "additional sources of information that might aid in focusing ATSDR's VI evaluation" are compiled (see Section 3.2) [underlining added for emphasis]; (iii) "various geographic information system (GIS) techniques" are explored; (iv) "the historic indoor air contaminant concentrations" are estimated and multiple statistics are determined for multiple time-periods of interest; and (v) various types of data are reviewed for 30 or more contaminants which lack toxicity values. ATSDR may want to re-visit the proposed sequence of its work plan, particularly if there are or may be resource or time constraints that could impede completing all tasks and evaluating all buildings with potential vapor intrusion threats.	Although the work plan is laid out sequentially, some tasks overlap and are occurring concurrently. If time or resources impede work progress at some point in the future, ATSDR will consider alternatives to overcome any barriers.

Reviewer	Reviewer Comment	ATSDR Response
	In light of ATSDR's stated interest in placing "a higher importance on identifying current exposures" – see page 1 – and focusing "its investigation on those areas most likely to be at risk currently for VI" – see Section 3.1.6 – [underlining added for emphasis], it is unclear why the work plan would not emphasize (or identify as a first phase of work): (i) compilation and/or simulation of groundwater concentrations[40] (e.g., three-year average groundwater concentrations) for the most recent feasible time period(s); (ii) compilation of measured indoor air concentrations for the most recent feasible time period(s)[41] from areas that have not been subject to contaminated drinking water[42], which can be shown to be primarily attributable to soil gas intrusion; and (iii) reliance upon these subsets of groundwater and indoor air data for purposes of identifying buildings or areas as having "high potential VI risk", "medium potential VI risk", and "no apparent VI risk" under current conditions.[43]	ATSDR proposed the Prioritization Scheme (Section 3.1) and Refined Analyses (Section 3.2) to assist in the categorization of buildings on the base of greatest concern for potential VI impacts. The VI database includes both buildings that currently exist and those that were demolished; this building status (current or past) is captured in the Prioritization Scheme in Table 2B, Appendix B, along with other pertinent information such as building use. The computer application will systemically review the substantial amount of information collected over the years and contained in the VI database. The Excel worksheet output will allow the agency to sort the buildings into a variety of categories, such as existing buildings and demolished buildings. In addition, the Prioritization Scheme captures in Table 4B, Appendix B, the timeframes with higher contaminant concentrations, which will be taken into account as part of ATSDR's evaluation. Once developed, the computer application can quickly compile all information, complete calculations for all timeframes, etc. ATSDR can then focus on the most recent data as it reviews the Excel computer application output data. Note however, although the agency will focus on identifying current VI exposures, ATSDR will not exclude past VI exposures with adequate data from its evaluation.

[40] In principle, kriging techniques could be used, as an alternative to three-dimensional fate and transport modeling, to simulate concentrations of chemicals of interest in shallow groundwater.

[41] In the interest of efficiency, it might prove worthwhile to first examine the available data for the 50 buildings that "have had multiple indoor air measurements at several times and sample locations" – see page 25 – and determine which of these measurements has contemporaneous and co-located soil gas and ambient air data, for purposes of demonstrating that the indoor air concentrations arise primarily from soil gas intrusion.

[42] As noted previously, there is an important caveat associated with relying upon building-specific measurements of vapor concentration in indoor air, which may be difficult to overcome. Specifically, in buildings that have been serviced by drinking water distribution systems that delivered contaminated groundwater, historic vapor concentrations of site-related contaminants are likely to be elevated in indoor air due to volatilization from drinking water, independent of any contribution from soil gas intrusion.

Reviewer	Reviewer Comment	ATSDR Response
	By contrast, the proposed tasks related to data compilation and the prioritization scheme incur effort associated with historic data that may be less meaningful for purposes of understanding current conditions (e.g., calculation of mean and 95%UCL values for contaminant concentrations in groundwater in the 1980s and 1990s – Section 3.1.5 – and documenting "past building occupancy, use and floor plans for unoccupied buildings and for demolished buildings" – Section 3.3.2). If, in fact, the most important objective is to identify and characterize current exposures via vapor intrusion, then the work plan warrants re-structuring and re-sequencing to align with that focus.	As stated originally in Section 1 of the work plan, "…ATSDR will place a higher importance on identifying current exposures although the agency will consider past exposures as data availability and resources allow." To clarify the agency's intent, ATSDR deleted the portion of the statement saying, "although the agency will consider past exposures as data availability and resources allow." The agency then added the sentence, "Although the agency will focus on identifying current VI exposures, ATSDR will not exclude past VI exposures with adequate data from its evaluation." Overall, the computer application will quickly compile information on all buildings without introducing biases (e.g., past versus current). Although ATSDR will place a higher importance on current potential VI risks as the Excel computer application outputs are reviewed, if the timeframe with the highest contaminant concentrations is many years ago (e.g., 1980s or 1990s) for a particular building and other lines of evidence also point toward a higher VI potential for the past, ATSDR will evaluate past potential indoor air exposures for that building.

[43] For example, a mathematical model of soil gas intrusion could be used to estimate the magnitude of vapor intrusion exposures within each area of interest for the most recent time-period. With such exposure estimates, it should be possible to inform and identify an objective scheme for ranking geographic areas (and specific buildings, if desired) for vapor intrusion potential under current conditions. Depending upon the degree of resolution sought in the identification of "high VI risk" versus "low VI risk" versus "no VI risk" areas, the modeling could initially consider a standard, generic building for each geographic area and consider a subset of chemicals of concern (e.g., TCE, which is said to be a primary and prevalent contaminant in shallow groundwater), instead of considering each building of interest and each contaminant of interest. If the "most recent feasible time-period" (for which groundwater concentrations are available) is not contemporary (e.g., not current for 2018), information about remedial efforts and progress and recent concentration trends could be developed subsequently (as part of a "refined analysis") to put the exposure and risk information in context for current building occupants.

Reviewer	Reviewer Comment	ATSDR Response
	As I understand it, the public health assessment program allows ATSDR scientists flexibility about the form of their response to public health issues at sites on EPA's National Priorities List. Consequently, the proposed focus on developing visual displays and explorations of site data – see, for example, Section 3.2.2 – using geographic information software (and expanding the database to include data that "might aid in focusing ATSDR's VI evaluation" – see opening paragraph of Section 3.2 [underlining added for emphasis]) would seem unobjectionable on procedural grounds. On the other hand, it is not apparent, in light of the reservations expressed above: (i) how generating and publishing a visualization of the results of the prioritization scheme – see, for example, Section 3.2.2 – yields a "framework that puts site-specific exposures and the potential for harm" via vapor intrusion into perspective for the community or public health officials; or (ii) why such a "framework" should be developed before health risks and potential health effects are characterized for buildings or time-periods of priority interest.	To further focus the VI analysis following the Prioritization Scheme, in Section 3.2.2 the agency discusses how it will explore various geographic information system (GIS) techniques, such as heat and thematic maps. The GIS products from this exploratory data analysis will only assist the agency in visualizing areas of the base containing buildings with a higher VI risk; these products are not intended to solely provide the "framework that puts site-specific exposures and the potential for harm via vapor intrusion into perspective for the community or public health officials." Actually, the building-specific conceptual models that will be supported by maps, narratives, and tables are the "framework" that will assist ATSDR in determining the public health implications of potential current and historical exposures to indoor air contamination that may have resulted from vapor intrusion into buildings on the base (see Section 3.3.2).
	I recommend including in the final work plan a graphical depiction of the known areas of groundwater contamination and "active" areas of the site (e.g., areas with currently occupied buildings, although individual buildings need not be shown at this initial/low level of resolution). The portion(s) of the sites where these two types of areas overlap might be referred to as the "area of potential vapor intrusion", or some such term that indicates where it is that the proposed work pertains.	The work plan was developed to describe ATSDR's plan for conducting its VI evaluation. As such, the agency has not yet developed any figures of the areas of groundwater contamination and active areas of the site for its VI evaluation; however, graphical depictions similar to those described in the Reviewer's comment will be included in the VI PHA.
	Similarly, but reflecting a higher level of spatial resolution, the work plan might also include a graphical depiction of illustrative, simulated concentrations (e.g., for dissolved-phase TCE) in shallow groundwater, based upon the "groundwater-flow and contaminant fate and transport models" or kriging techniques for the most recent simulated time period, along with contemporaneously available monitoring wells.	See previous response.
	I recommend that Figure 1A in Appendix A be labelled appropriately to explicitly connect it to CH2M's historic work/approach, rather than leave, by itself, any impression that the figure represents ATSDR's current approach, as described in the work plan.	ATSDR agrees and changed the figure title to "CH2M's Vapor Intrusion Evaluation Approach" as well as added a note to the figure stating "This figure shows the procedure CH2M followed when conducting its vapor intrusion investigation, which is different than ATSDR's approach (see also Section 2.3 of the main text)."

Reviewer	Reviewer Comment	ATSDR Response
	Finally, I would like to clarify that two terms will be used appropriately in the final work plan and subsequent reports. The work plan refers to "buildings with soil vapor extraction (SVE) systems" (see page 22) and "mitigation systems installed in 13 buildings" (see page 1). Typically, the term "soil vapor extraction" is used only to describe a remediation technique for soil located above the groundwater table; ordinarily, it would be implemented on an area- or community-wide basis, rather than building by building. "Vapor intrusion mitigation" generally refers to a broad range of response actions taken to reduce or eliminate human exposure to vapor-forming chemicals in a specific building arising from the vapor intrusion pathway, which generally accomplishes practically little or no remediation of subsurface conditions. Building mitigation options for soil gas intrusion may include: treating indoor air (e.g., adsorption using activated carbon); sealing major openings for soil gas entry, where known and identified; over-pressurizing nonresidential buildings by adjusting the HVAC system; increasing building ventilation, for example using fans or natural ventilation; and active depressurization technologies, such as sub-foundation depressurization systems.	ATSDR agrees with Reviewer 4 and will ensure the two terms are used appropriately in the final work plan and subsequent reports. In Section 3.3.2, the agency replaced "building with soil vapor extraction (SVE) systems" with "buildings with vapor intrusion mitigation systems".
5	See comments attached to electronic version of work plan provided for review.	Thank you for the comments and edits. ATSDR has reviewed and incorporated them into the PHA, where appropriate. Please see "Additional Document Comments" later in this table for Reviewer # 5 specific comments and ATSDR's responses.
6	P. 21. I would add summarizing available soil vapor data to the list of information to be complied and summarized in maps.	ATSDR agrees and in Section 3.3.2, specific tasks main bullet 2, the agency added another sub-bullet stating, "Summarize building-specific shallow groundwater and soil gas information previously compiled through the Prioritization Scheme and maps."

Reviewer	Reviewer Comment	ATSDR Response
	P. 5. Biodegradation should be considered for petroleum hydrocarbons. This has been well documented by both USEPA and ITRC and should be included in the analysis. As currently planned, the ATSDR analysis will overestimate potential risks from petroleum hydrocarbons.	In Section 3.1, ATSDR states the VI PHA will use the conservative assumption of no biodegradation. The agency modified the statement to indicate that the Prioritization Scheme will use the conservative assumption of no biodegradation. However, ATSDR will consider guidance, such as the USEPA's petroleum vapor intrusion guidance [USEPA 2015b], in the agency's building-specific public health evaluations (Section 3.3.2) with regard to fate and transport factors such as for biodegradation. For example, ATSDR will evaluate factors such as available information on building dimensions, depths to groundwater, concentrations, area of paving around buildings, and soil properties to assess the potential for biodegradation in high priority buildings where petroleum compounds are the primary concern.
	P. 6. It is unclear how many buildings ATSDR intends to evaluate in the VI database. It would be helpful to indicate at least an approximate number of buildings that may be included to understand the scale of the evaluation process.	ATSDR does not provide until later in the work plan the results of some preliminary queries (see Section 4, main bullet 4). The work plan states, "ATSDR's VI database is composed of about 14,000 buildings. However, environmental sampling data are not available for all buildings. Based on very preliminary queries of the VI database, ATSDR believes at least 1,500 buildings have at least some measured environmental data inside the buildings and/or within 100 ft of the buildings." Based on these preliminary queries, the computer application compiling data for the Prioritization Scheme will likely include output data for about 1,500 buildings.
	P. 8. ATSDR indicates that if the simulated groundwater results do not mimic shallow groundwater, those results will not be used. Is it not possible to adjust the model in some way? How is mimicking shallow groundwater defined? It is not at all clear what criteria will be used to retain or eliminate grids within the simulated groundwater data.	Mimic was a poor word choice. The work plan was updated to state, "…represent shallow groundwater (i.e., if the center point of the grid is ≤ 25 ft bgs)."
	P. 18. Although not shown on the calculation of the indoor air estimate, it will also be necessary to use the chemical specific Henry's law constant and a conversion factor in the equation.	ATSDR updated the work plan to include Henry's law constant.
	Table 6B first row indicates a zero will be given if there are no shallow groundwater data. Should this be soil gas data?	ATSDR updated the work plan to replace "shallow groundwater" with "soil gas" data in Table 6B, Appendix B.

What is your overall recommendation on this report?		
1	Recommend Approval	Thank you.
2	Recommend Approval with Required Changes	Thank you.
3	Recommend Approval with Required Changes	Thank you.
4	Approval Not Recommended: reservations about sequence of proposed work, in light of "priority" objectives (e.g., "those areas most likely to be at risk currently for VI"); proposed scheme to prioritize geographic areas and the relative importance attributed to it as a work product; and shortcomings in proposed approach for estimating vapor intrusion exposures. The foregoing comments indicate how and where the work plan could be improved to merit approval and implementation.	In addition to responding to comments by Reviewer 4 in this table, ATSDR modified the work plan, where appropriate, to address those comments. The agency will share the updated work plan and its responses to comments with Reviewer 4.
5	Recommend Approval with Required Changes	Thank you.
6	Recommend Approval with Required Changes	Thank you.
Recommended Changes		
2	The inhalation exposures from the groundwater/ drinking water supply should be combined with the inhalation exposure from vapor intrusion before evaluating the potential health effects.	ATSDR will qualitatively acknowledge contributions from inhalation exposure from past groundwater/drinking water supply via showering, dish washing, etc. Because calculating historical indoor air estimates for VI will introduce a large degree of uncertainty, the agency does not expect to combine past estimated VI inhalation exposures with the estimated inhalation exposures from groundwater/drinking water presented in the January 20, 2017 Public Health Assessment.
	The foundation construction should be considered in the building-specific conceptual models.	ATSDR will be gathering building-specific characteristics like construction that would indicate whether the building is slab on grade, basement, or elevated/crawl space (see Section 3.3.1, specific tasks bullet 2).
3	Clarity on objectives.	In Section 1, paragraph 3, ATSDR provides the objectives or purpose of the VI PHA. To provide clarity, the agency modified this paragraph to include bullets containing the objectives.
	Greater focus on key parameters, i.e., receptor exposures in Prioritization Scheme.	As stated in Section 3.1.6, ATSDR will perform sensitivity analyses. The main goal of sensitivity analyses is to gain insight into which assumptions are critical. The process involves various ways of changing input values of the computer application to see the effect on the output value. ATSDR agrees one key factor in assessing risk is a receptor's exposure. For the VI PHA, the exposure route is breathing the contaminants in indoor air. The

		agency intends to increase number of points assigned to Table 7B, Appendix B, Indoor Air Factor Analysis Chart, as part of its sensitivity analyses to ensure we focus on indoor air exposures in areas with likely VI risk.
	Incorporation of additional parameters needed to model indoor vapour concentrations including soil type, building properties such as Qsoil and ventilation rate. Use of normalized parameters such as those discussed in Hers et al. (2003) and Johnson (2005) (critical parameter paper may assist.)	In the J&E model, ATSDR will use the building-specific and soil-specific parameters that are available and will also use the critical parameters discussed in the proposed articles for comparison.
5	Clarify how historical exposure assessment will be used (I understand it is an objective of this study, but it is not clear why this assessment is necessary).	ATSDR will evaluate historical exposure levels to determine whether estimated indoor air levels in the past were potentially at levels that could harm health. Identifying past exposures is an integral part of the process, and is discussed in ATSDR's 2005 guidance manual [ATSDR 2005], which states (underline emphasis added) • **Section 2.1.3:** The public health assessment is used by ATSDR to identify possible harmful exposures and to recommend actions needed to protect public health…It considers <u>past exposures</u> in addition to <u>current and potential future exposures</u>. • **Section 6.1:** <u>Past, current, and future exposure conditions</u> need to be considered because the elements of an exposure pathway typically change with time.
	Include a bioattenuation factor for VICVs for petroleum hydrocarbons.	ATSDR will consider guidance, such as the USEPA's petroleum vapor intrusion guidance [USEPA 2015b], in the agency's building-specific public health evaluations (Section 3.3.2) with regard to fate and transport factors such as for biodegradation of petroleum hydrocarbons. For example, ATSDR will evaluate factors such as available information building dimensions, depths to groundwater, concentrations, area of paving around buildings, and soil properties to assess the potential for biodegradation in high priority buildings where petroleum compounds are the primary concern.
	Provide better description of use of simulated groundwater concentrations. Work plan currently states that simulated groundwater will be used if they "mimic" measured shallow groundwater concentrations. This is not clear.	Mimic was a poor word choice. The work plan was updated to state, "…represent shallow groundwater (i.e., if the center point of the grid is ≤ 25 ft bgs)." In general, the simulated shallow groundwater results are being used to supplement the measured results.
	Modify table 1B to include site chemicals of concern, CVs, and VICVs.	Instead of modifying Table 1B, Appendix B, ATSDR added two new tables. Table 9B, Appendix B, contains the CVs ATSDR will use to screen contaminants in indoor air. Table 10B, Appendix B, contains the VICVs the agency will use to screen contaminants in shallow groundwater and soil gas.

	Provide details on how prioritization results will be categorized into different risk categories.	To determine "high potential VI risk", "medium potential VI risk", etc., ATSDR will use technical expertise and professional judgment to evaluate the combination of contaminant scores (compiled from Tables 3B–7B, Appendix B) and building-specific factors (compiled from Table 2B, Appendix B) when determining each building's placement in one of the VI risk categories. The agency also added general definitions of the categories to Section 3.1, paragraph 5.
	Include more discussion of uncertainties of assessment.	The ATSDR VI evaluation process [ATSDR 2016] recommends the use of multiple lines of evidence to address the uncertainties inherent in the public health assessment of VI exposures. Section 4 of the work plan notes the limitations in the available data specific to Camp Lejeune, as well as limitations inherent to all VI evaluations. In general, ATSDR intends to use the J&E model and Kendall's Tau rank correlation coefficient in its assessment of uncertainties; further details will be provided in the VI PHA to describe the analyses and results.
	Editorial comment – Section 3.3.1: Calculations for indoor air concentrations based on groundwater concentrations need to include Henry's law coefficient.	ATSDR agrees and updated the work plan.
	Include assessment of indoor air concentrations based on soil gas measurements in Section 3.3.1.	Unlike groundwater data, there are very limited soil gas data available to assist with historical indoor air exposure estimates. Because there are so few samples, ATSDR does not expect the limited soil gas data from the past to be representative over space and time.
	Provide additional detail regarding the J&E model use.	The purpose of the work plan was to provide a general outline of the processes ATSDR will follow to complete the VI PHA. The current level of detail in the work plan regarding use of the J&E model is deemed sufficient for this purpose (see Section 3.3.1, specific tasks main bullet 9). Additional details, including model inputs, will be provided in the VI PHA.
6	Provide a flowchart or graph for the overall prioritization scheme.	To show how the pieces of the Prioritization Scheme approach fit together, ATSDR added three figures to Appendix A of the work plan: Figure 2A (ATSDR's Prioritization Scheme Directory Structure), Figure 3A (ATSDR's Prioritization Scheme High Level Data Flow), and Figure 4A (ATSDR's Priority Scheme Concurrency Diagram).
	Consider ranking or weighting some of the variables in the prioritization scheme that have been shown to have a greater influence on potential soil vapor and indoor air concentrations, such as groundwater concentration or distance to building.	As stated in Section 3.1.6, ATSDR will perform sensitivity analyses. The main goal of sensitivity analyses is to gain insight into which assumptions are critical. The process involves various ways of changing input values of the computer application to see the effect on the output value. ATSDR may modify its

		analysis so that the agency can focus its investigation on those areas most likely to be at risk currently for VI.
	Include documentation or values for the indoor air CVs to be used in the assessment.	ATSDR added Table 9B, Appendix B, which contains the CVs ATSDR will use to screen contaminants in indoor air, to the work plan.

Additional General Comments		
6	I didn't have time to look at many of the supporting documents. With a little more time, that could have been done.	Thank you for your timely review of the work plan.

Document Tracked Comments		
3	Section 1, paragraph 2, "The same contaminants that were present in drinking water at MCB Camp Lejeune are also thought to be of concern for vapor intrusion." There is limited discussion of source and no reference to possible DNAPL source zone.	Section 1 presents the scope of the VI PHA and is not intended to provide a detailed discussion of potential sources. Section 2.2, provides a short summary of the history of groundwater contamination at the base.
5	Section 1, paragraph 3, "…essentially, ATSDR will place a higher importance on identifying current exposures, although the agency will consider past exposures as data availability and resources allow." It is not clear how past exposures will be considered and/or findings of historical exposures will be used for decision making. Is this necessary?	The public health evaluation of estimated, historical exposures will follow standard procedures outlined in the ATSDR Public Health Assessment Guidance Manual [ATSDR 2005]. The evaluation of these past estimated exposures will address the concerns expressed to the agency and answer the question, "Could past site-related vapor intrusion indoor air exposures have harmed health?"
1	Section 2, paragraph 1, "The base is southeast of Jacksonville, NC and about 70 miles northeast of Wilmington, NC." Seems more like about 50.	After closer examination, the base is about 50 miles as stated by Reviewer 1. ATSDR updated the work plan to express the correct distance.

Document Tracked Comments		
3	Section 2.3, paragraph 2, "CH2M is using a phased approach consistent with guidelines in the Department of Defense Vapor Intrusion Handbook [DOD 2009], Interstate Technology & Regulatory Council guidelines [ITRC 2007], and USEPA vapor intrusion guidance documents [USEPA 2002, 2015]." Should reference ITRC 2014 Petroleum Vapor Intrusion Guidance.	Okay, added this reference to the work plan.
3	Section 3, number 2, "ATSDR will consider past, current, and future exposures, while CH2M is considering current and future exposures." How will past be done?	ATSDR will estimate past indoor air contaminant concentrations using groundwater-to-air attenuation factors (AFs) for buildings with sufficient shallow groundwater data (see Section 3.3).
1	Section 3, number 2, "ATSDR will use available information about demolished buildings while acknowledging thatknowing there are likely buildings that existed in the past that are not found in the currently available databases.	ATSDR made the requested edit to the text.
3	Section 3, number 2, "ATSDR's analyses will include demolished buildings and currently unoccupied buildings, which are not included in CH2M analyses that include only occupied buildings." Not clear why evaluation of demolished buildings would be useful?	ATSDR can evaluate the estimated contaminant indoor air concentrations to determine whether the levels were of public health concern for people who may have worked and/or lived in these demolished buildings in the past when they existed.
3	Section 3, number 2, "ATSDR's analyses will include demolished buildings and currently unoccupied buildings, which are not included in CH2M analyses that include only occupied buildings." Unoccupied buildings will have different characteristics with respect to vapor intrusion and therefore should be noted as such in database.	ATSDR agrees for current exposures, unoccupied buildings may have different VI characteristics. However, the agency can still evaluate the estimated contaminant indoor air concentrations to determine whether the levels were of public health concern for people who may have worked and/or lived in these currently unoccupied buildings in the past.
1	Section 3, number 3b, footnote 5, "ATSDR intends to use the J&E model to estimate reasonable ranges of attenuation factors based on a series of site-specific scenarios (as part of our estimation of past indoor air concentrations in Section 3.3.1)." I think this is a great approach that incorporates the uncertainty of site-specific parameters.	Thank you for your comment.

Document Tracked Comments		
1	Section 3.1, paragraph 1, "Given the size of the base, it is not feasible for ATSDR to perform separate VI evaluations on each of the approximately 14,000 buildings." Tree sampling, which covers a large area in less time than conventional approached for VOCs might be an additional approach to consider. The data is not as defensible, but great to include when trying to scan for VI potential over a large area.	For its VI PHA, ATSDR is evaluating currently available information and data. There are no tree sampling data available for MCB Camp Lejeune.
3	Section 3.1, paragraph 1, "ATSDR also notes that petroleum products can attenuate within shorter distances when aerobic conditions support biodegradation, but the planned VI PHA will use the conservative assumption of no biodegradation." Suggest inclusion of biodegradation be considered either through US EPA (2015) Petroleum Vapor Intrusion guidance or similar approach. This could be another line of evidence or method to interpret the significance of low concentration data.	In Section 3.1, ATSDR states the VI PHA will use the conservative assumption of no biodegradation. The agency modified the statement to indicate that the Prioritization Scheme will use the conservative assumption of no biodegradation. However, ATSDR will consider guidance, such as the USEPA's petroleum vapor intrusion guidance [USEPA 2015b], in the agency's building-specific public health evaluations (Section 3.3.2) with regard to fate and transport factors such as for biodegradation. For example, ATSDR will evaluate factors such as building dimensions, depths to groundwater, contaminant concentrations, area of paving around buildings, and soil properties to assess the potential for biodegradation in high priority buildings where petroleum compounds are the primary concern.
5	Section 3.1, paragraph 1, footnote 6, "Vertical soil gas profiling of petroleum vapors is necessary to confirm aerobic biodegradation, but the data can be difficult to evaluate. A variety of site-specific conditions (e.g., large building foundations and paved surfaces) can inhibit the supply of oxygen and the reaction [ATSDR 2016]." There is sufficient data in the literature regarding the consistency with which natural vadose-zone biodegradation mitigates the vapor intrusion potential for petroleum hydrocarbons. Ignoring this factor will result in a substantial positive bias of the vapor intrusion potential assessment for petroleum compounds (particularly at low concentrations). The decision to neglect biodegradation of petroleum compounds should be reconsidered (or at least be considered in the public health evaluation (Section 3.3.2).	See previous response.

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1	Section 3.1, paragraph 3, "The second set of criteria address factors specifically related to the sampling data, such as magnitude of contaminant concentrations and frequency of detections (see Tables 3B–7B, Appendix B)." What is special about 8 samples in Table 3B? Seems rather arbitrary, but I assume there has been rigorous statistical analysis that concludes 8 as a magic minimum number to make statistical inferences.	ATSDR's exposure point concentration workgroup simulated confidence limits coverage for more typical distributional assumptions and recommended a minimum of 8 samples, with at least 4 of those samples having detected results and at least 20% of the samples having detected results, as the floor for sample size to have a reasonable frequency of the upper confidence level (UCL) being within 10% of the true population mean. The agency expects guidance for estimating exposure point concentrations, which includes these recommendations for sample size, to be released soon. This information was added as a footnote to Table 3B, Appendix B. Note, a similar analysis was performed for proUCL that states "Just like other government documents (e.g., U.S. EPA 2009), various versions of ProUCL (2007, 2009, 2011, 2013, 2016) also make some rule-of thumb type suggestions (e.g., minimum sample size requirement of 8-10) based upon professional judgment and experience of the developers." [USEPA 2015a]
3	Section 3.1, paragraph 3, "For each contaminant, the agency will add together the points collected from each table and mark the total points for that building in the "Factor Analysis Results" section of Table 8B, Appendix B." Recommend indicating that high score = high priority.	A high score alone may or may not indicate high potential VI risk because ATSDR will evaluate other factors, such as the text from Table 2B, Appendix B, alongside the numerical scores to determine potential VI risk. No change was made to the work plan.
3	Section 3.1, last paragraph, "Overall, the Prioritization Scheme includes primary tasks such as development of the VI database." Perhaps is obvious but what actions will be taken based on the prioritization scheme	ATSDR will not use the Prioritization Scheme results to recommend actions be taken at the base. The scheme is only the first step in screening the VI data and determining potential VI Risk. Section 3.2 (Refined Analyses) and Section 3.3 (Data Evaluation) will provide additional information for ATSDR to evaluate to determine any needed actions to protect public health.
3	Section 3.1.1, specific tasks main bullet 3, sub-bullet 1, "Shallow Groundwater." Intermediate and deep groundwater data could be important for evaluation of the conceptual site model (e.g., diving plume, deeper sources).	The historical modeling effort developed models to characterize sources, groundwater flow, and groundwater contaminant transport for water-supply well operation. Essentially, the historical effort created a conceptual model that included both shallow and deep groundwater and how contamination moved throughout the modeled area. Conversely, ATSDR's focus for the VI PHA is on only shallow groundwater sources that may impact VI risk. Towards that end, the agency is including information, when relevant, from the historical modeling effort for Model Layer 1 that estimates contamination in the shallow groundwater.

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5	Section 3.1.1, specific tasks main bullet 3, sub-bullet 1, “Shallow Groundwater: Any groundwater sample taken from a depth less than 15 ft below ground surface (bgs). In addition, if a sample came from a well screened between 15–25 ft and the water level within the well was within 15 ft of the ground surface, that sample was also designated as shallow groundwater. ATSDR did not include groundwater samples screened from deeper than 25 ft as shallow groundwater.” There is some inconsistency in the depth intervals discussed in this work plan. I do not understand why data collected at depths up to 25 ft bgs are not included in this assessment. Better yet, can the data base be used to use all groundwater data collected within 5 ft of the water table elevation (within 10 ft is ok too if that works better).	At the start of the data extraction project, ATSDR used professional judgement and choose groundwater samples screened from a depth less than 15 ft below ground surface (bgs), as well as those screened between 15–25 ft when the water level within the well was within 15 ft of the ground surface, to be representative of shallow groundwater that may impact vapor intrusion into base buildings and incorporated those groundwater samples into the VI database. The agency used these shallow groundwater samples in our Prioritization Scheme. In Section 3.2.2, the work plan states the area investigation will consider additional information, such as main bullet 8: “If other information such as average depth to groundwater and groundwater well screening intervals are known for the area.” From this investigation, ATSDR will know which areas have a depth to groundwater (i.e., water table elevation) of around 5-10 ft, versus those with a depth to groundwater of 20-25 ft. The agency will take into account in our building-specific public health evaluations the depth to groundwater, and added “depth to groundwater” to Section 3.3.2, specific tasks main bullet 2, sub-bullet 1, sub-sub-bullet 5.
5	Section 3.1.1, specific tasks main bullet 3, sub-bullet 1, sub-sub-bullet 2, “the sample matched another sample in the VI database that was previously identified as “shallow groundwater.” I don't know what you mean here. Do you sample location matched another sample from this location that was previously identified as "shallow groundwater"?	Because there were frequently shallow, intermediate, and deep samples taken at the same location, ATSDR did not use location when matching samples. For that matching, the agency used the sample ID. The work plan text was updated to state “the sample ID matched another sample ID in the VI database…”
5	Section 3.1.1, specific tasks main bullet 3, sub-bullet 2, “Any data referred to as “indoor air” or “crawlspace air”…” It is not clear why you would include crawlspace air data as indoor air data. It would be better to have a clear data base and identify these as crawl space data. This can be an additional line of evidence if crawlspace concentrations are significantly different from indoor air concentrations. Note the USEPA database has limited crawl space data to justify the generic attenuation factor of 1.	There are only 6 samples designated as crawlspace (i.e., less than 1% of the air samples). ATSDR made the decision to include these crawlspace air samples with the indoor air data for the Prioritization Scheme. However, for the building-specific public health evaluations (Section 3.3.2), ATSDR intends to review the sub-categories and sample locations more closely, which includes looking at the crawlspace and indoor air contaminant concentrations separately.

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1	Section 3.1.1, specific tasks main bullet 3, sub-bullet 2, "For air data with no further information regarding the type of air sample collected, ATSDR compiled these data as indoor air if the sample location appeared to be within a building footprint." I would assume this includes subslab samples. Might explicitly state that here if that is the case.	Subslab samples were typically referred to as "subslab soil gas" samples in the site's documents. This type of sample was included under the category of "soil gas" not "indoor air". ATSDR updated the work plan under the soil gas category to add the term "subslab soil gas".
3	Section 3.1.1, specific tasks main bullet 3, sub-bullet 4, "Any data referred to as "soil gas," "soil vapor," or "vapor" within the source documents." Are there subslab vapor data and if so are these data analyzed separately.	For the Prioritization Scheme, ATSDR did not distinguish subslab vapor samples (collected under building foundations) from outdoor soil gas samples. However, for the building-specific public health evaluations (Section 3.3.2), ATSDR intends to review the sub-categories and sample locations more closely, which includes looking at the subslab and outdoor soil gas contaminant concentrations separately.
5	Section 3.1.1, specific tasks main bullet 3, sub-bullet 4, "ATSDR did not compile data classified as "air sparging/soil vapor" as soil gas." I don't know if we need to repeat here, but SVE system data should not be included in this category either.	In the outdoor air category (Section 3.1.1, specific tasks main bullet 3, sub-bullet 3), the agency states "exhaust" data and "soil vapor extraction system" data were not included…", but ATSDR agrees it is appropriate to repeat that "soil vapor extraction system data" are not included in the soil gas category either.
5	Section 3.1.2, specific tasks main bullet 1, sub-bullet 1, "Steady-state (predevelopment) simulated groundwater level data for the Tarawa Terrace, HPIA and landfill models." I am not familiar with the modeling, but it is not clear how pre-development results will be used in this assessment. If they will not be used, just be clear (otherwise, clarify what time periods the steady-state results will be used for).	ATSDR plans to compare the steady-state (predevelopment) simulated groundwater level data to the transient-state (pumping) simulated groundwater level data in each modeled area to determine for the shallow groundwater which areas groundwater levels were impacted the most by pumping and how this may have impacted VI.
3	Section 3.1.2, specific tasks main bullet 2, "Determine whether the simulated groundwater results for each grid mimic shallow groundwater (i.e., if the center point of the grid is ≤ 25 ft bgs)." Will a statistical criteria be used for paired comparisons?	Where possible, for the VI PHA, ATSDR plans to compare simulated shallow groundwater results for Model Layer 1 with measured shallow groundwater results for similar locations and time frames to determine how well the simulated concentrations are similar to the measured concentrations (most likely using a Kendall's Tau rank correlation coefficient, t-test, and/or Wilcoxon signed rank test.) This information was added to Section 4, main bullet 2, sub-bullet 1.

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5	Section 3.1.2, specific tasks main bullet 2, sub-bullet 1, "If the simulated groundwater results for the grid do not mimic shallow groundwater, the agency will not use that grid's results in the VI PHA." This is not clear to me. Provide a quantitative threshold for "mimic". Also, should this exclusion of modeled data extend beyond the individual grid? What will be done if there are hundreds of grids between locations with measured results? This sentence suggests that only 1 modeled grid will not be used.	The quantitative threshold was provided in the main bullet that this sub-bullet is under; specifically, this main bullet stated, "Determine whether the simulated groundwater results for each grid mimic shallow groundwater (i.e., if the center point of the grid is ≤ 25 ft bgs). Similar to the measured data, the threshold for the simulated results to be considered "shallow groundwater" is ≤ 25 ft bgs. In addition, ATSDR believes the word "mimic" is confusing and has changed it to "represent" here and in other sections of the work plan. Note, previously the work plan indicated that, "For the models, the simulated contaminant concentrations are for the center of each grid; however, for the VI PHA, ATSDR will assume this concentration is the same for the entire grid." After talking further with the modelers, this assumption was determined to be in error. ATSDR has deleted the text in the sentence beginning with "however". Additionally, the simulated results encompass only a small portion of the base. The measured results cover a much larger area. To determine whether the simulated results for shallow groundwater are similar to the measured results for shallow groundwater, ATSDR will compare simulated and measured results where the locations and time frames correspond. If the simulated groundwater results for Model Layer 1 do not closely match the measured shallow groundwater results, the agency will not use the simulated contaminant results in the VI PHA.
1	Section 3.1.2, specific tasks 1st and 3rd main bullets and sub-bullets, [work plan text not provided here because it is too long]. I don't think I understand why the groundwater level and concentration data is being subsetted like it is. Maybe those are just the date ranges those data are available? If data is being excluded for a certain reason, the reasoning should be stated.	Correct, the date ranges for the groundwater level and simulated contaminant concentration data are based on what information was available from the modelers. ATSDR has added this statement to the first paragraph in Section 3.1.2, "With regard to the simulated data, results were available for a variety of time periods and contaminants; the agency compiled simulated results that were readily available."
1	Section 3.1.2, specific tasks 3rd and 4th main bullets and sub-bullets, [work plan text not provided here because it is too long]. There is mention of compiling the groundwater level data so those dates make sense, but there is no mention of how the concentration data will be compiled. I might have missed it though.	ATSDR staff who worked on the historical modeling effort are gathering and processing the simulated data that are contained in the agency's files.

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3	Section 3.1.3, specific tasks main bullet 1, "Compile building use information such as workplace, warehouse, storage, school, residence, health care, or unknown." Would it be possible to obtain information on building HVAC system, i.e., gas-fired furnace or electric heat for smaller residential buildings, type of ventilation for larger buildings. Given the diverse buildings on the base some may have systems that could have a significant influence on vapor intrusion.	ATSDR agrees heating, ventilating, and air conditioning (HVAC) system data are important to gather; unfortunately, these data are not available electronically at this time to include in the VI database. However, CH2M documents include information on HVACs, building size, building ceiling height, etc. for some of the buildings at the base [CH2M 2008, 2009, 2011]. For those buildings, ATSDR plans to extract information from these documents for inclusion in our VI PHA evaluation.
3	Section 3.1.3, specific tasks main bullet 3, "Using the building footprint, record the approximate size of the building footprint." Also recommend obtaining data on building foundation, e.g., basement, crawlspace, slab at grade.	Building foundation data, e.g., basement, crawlspace, slab at grade, are not available electronically to include in the VI database, ATSDR will work with MCB Camp Lejeune to gather this information on the subset of buildings the agency plans to further evaluate (see Section 3.3.2, specific tasks main bullet 2, sub-bullet 4).
5	Section 3.1.3, specific tasks main bullet 4, sub-bullet 1, "Record whether each building is above or within 100 ft of free product in the groundwater." Please add some text to clarify definition of free product (because different people use different definitions). I assume this is floating LNAPL for petroleum releases and not DNAPL.	Correct, free product refers to fuel-related light non-aqueous phase liquids (LNAPL) that are at the groundwater table. There are three locations within the HPIA that had significant subsurface LNAPL contamination: the Hadnot Point Fuel Farm (HPFF), Building 1115 area, and Building 1613 area. This information was added to the work plan in Section 3.1.3, footnote 9.
3	Section 3.1.3, specific tasks main bullet 4, sub-bullet 1, footnote 9, "…with simulated saturation values in percent ranging from 0 to 0.208 (0 to 20.8%). The upper value of ~20% indicates that LNAPL occupies all of the pore spaces between soil grains (20% is the effective soil porosity estimated for the site)." This may not have implications for the vapor intrusion investigation but for completeness it is noted that a LNAPL saturation equal to the total porosity is not possible as LNAPL exists as a multiphase in soil. There is extensive data and science to support this (e.g., ITRC 2009 LNAPL guidance and 2018 update). A total porosity of 20.8% is relatively low and therefore a possible explanation is that total porosity is actually higher.	ATSDR updated the second statement to say, "The upper value of ~20% indicates that LNAPL occupies *most* of the pore spaces between soil grains." [italic emphasis added] For the Prioritization Scheme, ATSDR is using the presence/absence of free product, not the actual values of thickness or saturation. As stated in the footnote, the historical modeling effort simulated both thickness results and percent saturation results. Because the footprint (horizontal extent) of the LNAPL thickness and saturation profiles are similar, either set of results can be used to determine whether a building is above or near free product in the HPIA. Note, free product measurements from the historical reports are also available.

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5	Section 3.1.3, specific tasks main bullet 4, sub-bullet 3, "For four time periods of measured data (1980s, 1990s, 2000–2007, 2008–2013), compile information on how many shallow groundwater and soil gas samples were collected within 100 ft of each building, and how many indoor air samples were collected from inside each building." Consider including contoured data into the assessment.	This sub-bullet refers to number of samples to be collected for the factor analysis charts in Appendix B, such as Table 3B, Appendix B, Frequency of Results Factor Analysis Chart. ATSDR has draft guidance for estimating exposure point concentrations, which recommends that a contaminant be detected in a minimum of 8 samples, with at least 4 of those samples having detected results and at least 20% of the samples having detected results, to calculate a mean contaminant concentration and 95% UCL of the mean. A variety of products, including contoured data in the form of maps, are being considered as a part of the building-specific conceptual models described in Section 3.3.2 (Public Health Evaluation).
5	Section 3.1.3, specific tasks main bullet 4, sub-bullet 4, "For the four time periods of measured data, compile the rate of detection for shallow groundwater and soil gas within 100 ft of each building, and indoor air inside each building." Also check if there are a significant number of data points where the analytical reporting limit is greater than the VICV.	Similar to the previous response, this bullet refers to information collected for the factor analysis charts in Appendix B. ATSDR has draft guidance for estimating exposure point concentrations, which states that the contaminant be detected >20% of the time to calculate mean contaminant concentration and 95% UCL of the mean. In Section 3.1.5, specific tasks main bullet 5, sub-bullet 1, sub-sub-bullet 1, ATSDR added text to the work plan to state the agency will determine "…if there are a significant number of data points where the analytical reporting limit is greater than the groundwater and soil gas VICVs, and air CVs."
1	Section 3.1.3, specific tasks main bullet 4, sub-bullet 4, "For the four time periods of measured data, compile the rate of detection of COPCs? for shallow groundwater and soil gas within 100 ft of each building, and indoor air inside each building.	ATSDR did not add the yellow highlighted text to the statement because the agency is compiling the rate of detection of all VOC contaminants near each building, not just COPCs.
5	Section 3.1.4, paragraph 1, "ATSDR will compile available residential air health-based comparison values (CVs) for the 162 compounds thought to be sufficiently volatile to potentially pose a health risk via vapor intrusion (see Table 1B, Appendix B)." Include CVs and VI CVs in this table. What is the assumed exposure duration for the CVs? Is this something else that should be considered for the Public Health Response Assessment?	In response to this comment, ATSDR added Tables 9B and 10B, Appendix B, which provide the CVs and VICVs the agency will use to screen the data. ATSDR CVs are generally available for three specified exposure periods: acute (1–14 days), intermediate (15–364 days), and chronic (365 days and longer) [ATSDR 2005]. Along with other factors, exposure duration is considered in the agency's public health evaluations.

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5	Section 3.1.4, paragraph 2, "…ATSDR will use the groundwater VICVs and the simulated shallow groundwater data to develop estimated plume boundaries to determine whether buildings are above or near estimated plume boundaries." This is not clear to me. Are you saying that the plume boundary will be based on groundwater concentration = GW VICV? You may want to clarify this sentence.	ATSDR deleted the sentence because the agency is no longer going to use the simulated shallow groundwater results to estimate plume boundaries. Instead, ATSDR will use preliminary information received from the Navy to determine the boundaries of potential shallow and surficial groundwater plumes on the base.
1	Section 3.1.4, specific tasks main bullet 2, "…where the USEPA Groundwater Attenuation Factor (AF_{USEPA}) is 0.001 and the Unit Conversion Factor is 1,000 liters per cubic meter (L/m^3) [ATSDR 2016]." 0.001 is the recommended value for generic groundwater than is greater than 5 ft below foundation. Because you have portions of the site where the depth to groundwater is less than 5 ft, this might not be an appropriate attenuation factor at those locations. **TABLE 6-1 RECOMMENDED VAPOR ATTENUATION FACTORS FOR RISK-BASED SCREENING OF THE VAPOR INTRUSION PATHWAY**[184] Sampling Medium — Medium-specific Attenuation Factor for Residential Buildings **Groundwater**, generic value, <u>except</u> for shallow water tables (less than five feet below foundation) or presence of preferential vapor migration routes in vadose zone soils — 1E-03 (0.001) **Groundwater,** specific value for fine-grained vadose zone soils, when laterally extensive layers are present[185] — 5E-04 (0.0005) **Sub-slab soil gas**, generic value — 3E-02 (0.03) **"Near-source" exterior soil gas**, generic value <u>except</u> for sources in the vadose zone (less than five feet below foundation) or presence of routes for preferential vapor migration in vadose zone soils — 3E-02 (0.03) **Crawl space air**, generic value — 1E-00 (1.0) USEPA, *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. In Office of Solid Waste and Emergency Response, Ed. **2015**; p 267.	ATSDR agrees that the attenuation factors may need to vary when depths to groundwater are less than 5 ft, and will assume no attenuation is occurring. This assumption will be used in the sensitivity analyses (see Section 3.1.6), and in ATSDR's public health evaluations (see Section 3.3.2), when appropriate.

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1	Section 3.1.4, specific tasks main bullet 3, "…where the USEPA Soil Gas Attenuation Factor is 0.03 [ATSDR 2016]." Again, appropriate for soil gas generally, but if there are locations where the source zone was found to be or is suspected to be in the shallow subsurface (less than 5 ft below foundation) then this might need to be modified.	See previous response.
3	Section 3.1.5, paragraph 1, "ATSDR will compile data and calculate initial summary statistics for the measured data, like mean and 95% upper confidence levels (UCL) of the mean contaminant concentrations, using the VI database." Will statistical parameters be calculated for individual buildings only, or for multiple buildings? (note there are additional considerations if multiple buildings are considered). If there are repeat indoor air data for a building will trend analysis be performed to evaluate if there are concentration trends?	Statistical parameters will be calculated for individual buildings, not multiple buildings. With regard to concentration trends for indoor air, as stated in Section 4 (bullet 8), "Although about 50 buildings have had multiple indoor air measurements at several times and sample locations, at this time, ATSDR does not know whether these data will meet the agency's data requirements for an evaluation of seasonal variability."
1	Section 3.1.5, paragraph 1, "For the ATSDR simulated data, monthly contaminant concentrations will be averaged over a rolling 3-year period for each grid. For the GA Tech simulated data, yearly averages will be calculated for each grid." I do not think I see the reasoning for averaging over a 3-year window in one instance and not the next. Is the ATSDR data more noisy than the GA Tech data?	ATSDR averages the data based on the results available to the agency. Note, the work plan was updated because after receiving the simulated results, only monthly data for the GA Tech effort are useful for the VI evaluation. • For the ATSDR-modeled data, the agency has available monthly simulated results for 40+ consecutive years. These concentrations are averaged over a rolling 3-year period similar to the Camp Lejeune Drinking Water PHA. • For the GA Tech-modeled data, the agency has available only a few monthly simulated results, not consecutive years of monthly results.
5	Section 3.1.5, paragraph 1, "For the ATSDR simulated data, monthly contaminant concentrations will be averaged over a rolling 3-year period for each grid. For the GA Tech simulated data, yearly averages will be calculated for each grid." I am not familiar with the modeling. Is there any overlap in the areal extent of the ATSDR and GA Tech models? If no overlap, than no further explanation necessary. If there is overlap, then explain if one model has precedence over the other.	See previous response. Yes, there is overlap in the areas the models cover; however, one model does not have precedence over the other. The Prioritization Scheme will chose the highest monthly contaminant concentration for each time frame regardless of which model the value is from. Section 3.1.2 described the modeled data available for the VI PHA.

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3	Section 3.1.5, paragraph 1, footnote 14, "The GA Tech simulated data available to ATSDR include monthly concentrations for specific nonconsecutive years; therefore, a rolling average cannot be calculated." From footnote it is not clear whether the dataset that is available will allow for yearly averages to be calculated.	ATSDR averages the data based on the results available to the agency. Note, the work plan was updated because after receiving the simulated results, only monthly data for the GA Tech effort are useful for the VI evaluation.
3	Section 3.1.5, paragraph 1, "For the GA Tech simulated data, yearly averages will be calculated for each grid." Or building if indoor air?	The modeling effort provides historic shallow groundwater data, not indoor air data.
5	Section 3.1.5, paragraph 1, "The agency will use the summary statistics to screen available indoor air, soil gas, and shallow groundwater measured data, as well as simulated estimates of contaminants in shallow groundwater ~~and soil gas~~, against CVs and VICVs." Table 6B does not include simulated estimates (so either delete here or add to Table 6B)	Thank you for catching this error. The yellow highlighted text was deleted from the work plan.
5	Section 3.1.5, paragraph 2, "The exceedance of a CV does not indicate health effects are likely, rather the exposure warrants further assessment to determine their potential to impact health." This is a very important sentence to communicate with community stakeholders. Is it worthwhile to italicize or underline this sentence?	As requested, ATSDR italicized the sentence in the work plan.
5	Section 3.1.5, specific tasks main bullet 1, sub-bullet 2, "For example, a concentration of 2 micrograms per cubic meter (μg/m^3) that is time-adjusted for a 10-hour workplace exposure would be modified by a factor of 0.41 (or 10 hours/24 hours) to calculate an air concentration of 0.82 μg/m^3." This suggests a 70-hour work week. Is that what you want?	To initially screen workplace indoor air data for the Prioritization Scheme (Section 3.1), ATSDR guidance recommends a conservative time-adjusted 10-hour workplace exposure modification factor of 0.41 [ATSDR 2016]. This 10-hour workplace adjustment will be used for evaluating acute/short-term exposures. For chronic/long-term exposures, the measured indoor air concentrations will be time-adjusted for a 10-hour, 5-day workplace exposure, which is a modifying factor of 0.30 (or 10 hours/24 hours × 5 days/7days).

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5	Section 3.1.5, specific tasks main bullet 1, sub-bullet 2, "These "adjusted-measurements" for workplace buildings will be used for the remainder of the VI PHA evaluation (e.g., in the next task, the mean will be calculated with the adjusted-measurement concentrations for workplace indoor air)." This should be indicated in a footnote in Table 7B.	ATSDR added a text footnote to Table 7B, Appendix B, about "adjusted-measurements" for workplace indoor air.
3	Section 3.1.5, specific tasks main bullet 2, sub-bullet 1, "For each contaminant sampled from shallow groundwater wells within 100 ft of a building, the agency will calculate mean contaminant concentrations for four time periods of measured data (1980s, 1990s, 2000–2007, 2008–2013)." An approach that utilizes all data within 100 ft maximizes the data quality but may reduce precision. A more targeted screening approach where if available data in the immediate area of a building may be more representative and precise indicator.	ATSDR's VI guidance suggests 100 ft as the target distance [ATSDR 2016]. However, as part of its sensitivity analyses (see Section 3.1.6), ATSDR plans to change the distance (e.g., within 25 ft, 50 ft, and 75 ft of the building) to determine whether the distance assumption is critical to the evaluation and to see the effect on the output values.
5	Section 3.1.5, specific tasks main bullet 2, sub-bullet 1, "If there are fewer than 8 samples for a given time period, ATSDR will not calculate a mean; the contaminant's maximum value will be used to represent the mean value in these instances." This may just be semantics, but I think you mean that the max value will be used instead of the mean value (I don't think it is representative of mean, but I don't object to max being used instead of the mean).	ATSDR agrees and replaced "…to represent the mean" in the text of the work plan with "…in place of the mean…." here and in other places in the work plan.
3	Section 3.1.5, specific tasks main bullet 2, sub-bullet 2, sub-sub-bullet 1, "However, the contaminant's maximum value will be used in place of ~~to represent~~ the 95% UCL value in these instances…"	See previous response (change accepted).
5	Section 3.1.5, specific tasks main bullet 2, sub-bullet 2, sub-sub-bullet 1, "However, the contaminant's maximum value will be used to represent the 95% UCL value in these instances…" This may just be semantics, but I think you mean that the max value will be used instead of the 95%UCL value (I don't think it is representative of 95%UCL, but I don't object to max being used instead of the 95%UCL).	ATSDR agrees and replaced "…to represent the 95% UCL" in the text of the work plan with "…in place of the 95% UCL…." here and in other places in the work plan.

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3	Section 3.1.5, specific tasks main bullet 2, sub-bullet 2, sub-sub-bullet 1, sub-sub-sub-bullet 3, "There are more than 80 percent nondetects for a given time period." What is the procedure used to handle nondetects in the analysis, i.e., substitution, Kaplan-Meier?	ATSDR has draft guidance for estimating exposure point concentrations, which provides the detailed procedures for handling nondetects in the analyses. Unfortunately, ATSDR cannot share this draft guidance until formally cleared by the agency. Overall, the procedures depend on the number of samples within the exposure unit and the number of detected samples. When there are > 80% nondetects for a given time period, the contaminant's maximum value will be used in place of the 95% UCL value in these instances. When there are ≤ 80% nondetects for a given time period, ATSDR will use R to calculate 95% UCLs. The packages in R for these calculations include EnvStats and NADA (nondetects and data analysis for environmental data). For further information, note that Helsel [2012] provides discussion of statistical approaches one can use to analyze environmental data sets containing nondetect (e.g., censored) data. Much of ATSDR's guidance is based on these approaches.
3	Section 3.1.5, specific tasks main bullet 2, sub-bullet 3, "A large coefficient of variation (greater than 100% or 200%) may be indicative of significant changes in contaminant concentrations across either space or time." Suggest conducting trend analysis.	ATSDR does not plan to conduct trend analyses for shallow groundwater, soil gas, or indoor air as part of the Prioritization Scheme. That said, in Section 3.3.2 the agency will summarize building-specific shallow groundwater, soil gas, and indoor air information previously compiled through the Prioritization Scheme and maps to examine the potential for VI, which includes noting trends. Also, ATSDR plans to explore the variation in indoor air measurements with regard to the seasons for about 50 buildings, as data representativeness allow.
5	Section 3.1.5, specific tasks main bullet 2, sub-bullet 3, "A large coefficient of variation (greater than 100% or 200%) may be…" These seem small to me, but you address this in the sensitivity analysis later, so I am ok with what you have proposed (I am also ok if you increase these values now).	As Reviewer 5 indicates, ATSDR intends to change the coefficient of variation during the sensitivity analysis; therefore, no change was made to the work plan.

Document Tracked Comments		
1	Section 3.1.5, specific tasks main bullet 4, footnote 19, "The grid must represent shallow groundwater (i.e., the center point of the grid must be ≤ 25 ft bgs)." Since this footnote is the same as 18, you could probably use the same superscript for both and have one footnote entry.	Change made (footnote 19 is now listed as footnote 18).
3	Section 3.1.5, specific tasks main bullet 5, "Screen the shallow groundwater, soil gas, and indoor air data on a building-by-building basis." For ease of describing screening a table may be useful.	ATSDR finds that the explanatory text in Section 3.1.5 describing the screening process is appropriate. However, the agency added Tables 9B and 10B, Appendix B, which provide the CVs and VICVs used for screening.
5	Section 3.1.6, specific tasks main bullet 1, "Changing the time periods for calculations (e.g., 1980–1984, 1985–1989, 1990–1995, etc.)" I am not sure what we get from this.	Because the time periods selected in the work plan are somewhat arbitrary, the agency decided to vary the periods to see if the changes effect the output of the Prioritization Scheme.
5	Section 3.1.6, specific tasks main bullet 5, "Running the computer application with measured indoor air, shallow groundwater and soil gas data only (i.e., do not include shallow groundwater simulated data.)" I like this step.	Thank you for your comment.
5	Section 3.1, general question. Did I miss it, or is there discussion in Section 3.1 about categorizing buildings into "high", "medium", "low", "no apparent", or "unknown" VI Risk. How will you break out these categories? Is this based on numerical score (if so, what is the score) or percentages (i.e., "high" = top 25% of buildings) I think you need to do something so all 1500 buildings are not "high potential VI Risk".	ATSDR discussed building placement into VI risk categories in Section 3.1, paragraph 5. Overall, ATSDR will use technical expertise and professional judgement to evaluate the contaminant scores (compiled as *numerical scores* from Tables 3B–7B, Appendix B) and building factors (compiled as *text* from Table 2B, Appendix B) found in Table 8B, Appendix B, when determining each building's placement in one of the VI risk categories. ATSDR does not expect 1,500 buildings to fall into the "high potential VI risk" category, and will work with Camp Lejeune to address that happenstance if it occurs.

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1	Section 3.2.1, paragraph 1, "Because CH2M used a different approach to determine which buildings had the greatest potential for VI, ATSDR will compare the buildings identified by its Prioritization Scheme to the building list developed by CH2M to determine whether CH2M identified any buildings that ATSDR did not; if so, ATSDR will include these CH2M buildings in its evaluation." I would think there is the possibility that a building(s) included in CH2M's list and not ATSDR's might be viewed as a classification error on CH2M's part. It might be good to change the language to indicate that those buildings will be evaluated by ATSDR for potential inclusion. This would give flexibility in the event that a building was misclassified using CH2M's approach.	ATSDR agrees and changed the language in the work plan to state, "if so, ATSDR will evaluate whether these CH2M buildings should be included in the Prioritizations Scheme as having the potential for VI."
5	Section 3.2.1, paragraph 1, "Because CH2M used a different approach to determine which buildings had the greatest potential for VI, ATSDR will compare the buildings identified by its Prioritization Scheme to the building list developed by CH2M to determine whether CH2M identified any buildings that ATSDR did not; if so, ATSDR will include these CH2M buildings in its evaluation." I don't think this should be a blanket statement. If CH2M found insignificant exposures in these buildings, then I don't think you need to automatically include these.	The focus is on buildings with the potential for VI (see previous response and changes made to the sentence.)
5	Section 3.2.1, main bullet 1, "ATSDR uses residential health-based CVs." I don't have a sense whether this is a reasonable assumption. I assume you are making this assumption because workplace buildings may be residential (or sensitive receptor) buildings in the future. Is this always true? Are there areas where sensitive receptor exposures are very unlikely in the future?	ATSDR only derives residential health-based CVs; the agency does not derive workplace values where there is a less than 24-hour exposure (i.e. non-continuous, occupational exposure). To screen workplace exposures with its residential health-based CVs, the agency adjusts the measured indoor air contaminant concentrations to account for a less than 24-hour exposures.
1	Section 3.2.2, "Area Investigation" If information is available on soil type (e.g., sandy, clayey, etc) then the union of areas with permeable soils (e.g., gravels, sands, etc) with the groundwater plume could also be areas to focus efforts. I think the union is important here, because soil type in and of itself is not indicative of higher potential VI.	Soil characteristics are one factor ATSDR will use the J&E model, along with building and groundwater characteristics (see Section 3.3.1, specific tasks bullet 9).

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1	Section 3.2.2, main bullet 1, "If there is an estimated shallow groundwater plume in the area…" I think it would be helpful to know the distance between the centroid of the plume or a focused polygon of "high" contaminant concentration and each building with the logic that buildings directly over the largest concentrations of a contaminant are at higher potential risk.	ATSDR agrees that the building's distance from sources of high contamination is one factor for assessing VI risk. For its initial assessment, the agency will focus on buildings located within 100 ft of a shallow groundwater plume or free product plume, and consider other distances in its sensitivity analysis. ATSDR's building-specific conceptual models will be supported by maps, which will visually show the location of the building with respect to plumes if applicable (see Section 3.3.2, specific tasks main bullet 2).
3	Section 3.2.2, main bullet 2, "If the time periods with highest chemical concentrations in one environmental medium coincide with the time periods with the highest concentrations in the other environmental media (i.e., soil gas and indoor air, shallow groundwater and soil gas, shallow groundwater and indoor air, and all three media together)." Seasonal analysis will be important to enable these comparisons to be made. Also consider whether there could be a time lag in surface expression of concentrations compared to when soil vapours were generated.	ATSDR agrees that seasonal analysis is important and that there may be a time lag; the agency will consider these factors in our evaluation.
5	Section 3.2.2, main bullet 2, "If the time periods with highest chemical concentrations in one environmental medium coincide with the time periods with the highest concentrations in the other environmental media (i.e., soil gas and indoor air, shallow groundwater and soil gas, shallow groundwater and indoor air, and all three media together)." OK to track this, but I don't see how this will help in the assessment.	The relative concentrations within various media can help identify potential sources of contamination. For example, if low or nondetect contaminant concentrations in soil gas with high contaminant concentrations in indoor air were found in the 1990's, the source is more likely an indoor or outdoor source, not a VI source.
5	Section 3.2.2, main bullet 3, "If the contamination was detected in indoor air, but was either not detected in shallow groundwater and soil gas or was detected at much lower concentrations in these media." What about the opposite? Chemicals detected in soil gas/groundwater but not in indoor air.	ATSDR added "and vice versa" to the end of the sentence.

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3	Section 3.2.2, main bullet 6, "If there is a significant indoor contaminant source in specific buildings." The potential for significant indoor contaminant source in buildings is referred to twice in document but is not clear how this will be determined. Understand of background sources could be critical to interpretation of data. Evaluation of chemical constituent and pathway samples may provide for lines of evidence to evaluate potential background.	MCB Camp Lejeune is aware ATSDR would like further information on significant indoor air sources for base buildings and have begun compiling building-specific information for the agency. ATSDR can assess residential background indoor air concentrations using a USEPA report, *Background indoor air concentrations of volatile organic compounds in North American residences* (1990–2005): a compilation of statistics for assessing vapor intrusion [USEPA 2011].

1	Section 3.2.2, specific tasks main bullet 2, "Conduct exploratory data analysis, including the creation of GIS maps of the base, to determine areas where buildings with "high potential VI risk," "medium potential VI risk," and "low potential VI risk" are located; also, create labels (i.e., Area 1, Area 2, etc.) encompassing buildings in the same area." An additional method that might be considered is tree sampling. There is a large body of knowledge indicating that trees sampling the shallow subsurface and provide quasi-quantitative, multi-phase information. Ideally this could be used in determining the areas of high/medium/low risk or used to add confidence to risk determinations posterior. Large areas can also be covered in a relatively short period of time. Vroblesky DA. User's Guide to the Collection and Analysis of Tree Cores to Assess the Distribution of Subsurface Volatile Organic Compounds2008. 59 p. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001FRJ.TXT Wilson, J.L., Samaranayake, V.A., Limmer, M.A., Burken, J.G. 2018. Phytoforensics: trees as bioindicators of potential indoor exposure via vapor intrusion. PlosONE. DOI: 10.1371/journal.pone.0193247. Wilson, J.L., Limmer, M.A., Samaranayake, V.A., Burken, J.G., 2017, Directional Tree Sampling to Locate Soil and Soil-Gas Plumes with Applications in Vapor Intrusion Assessment: Environmental Science and Technology, v. 51, no. 24, p. 14055-14064. DOI:10.1021/acs.est.7b03466. http://pubs.acs.org/doi/10.1021/acs.est.7b03466. Wilson, J.L., Limmer, M.A., Samaranayake, V.A., Schumacher, J.G., Burken, J.G., 2017, Tree Sampling as a Method to Assess Vapor Intrusion Potential at a Site Characterized by VOC-Contaminated Groundwater and Soil: Environmental Science and Technology, v. 51, no. 18, p. 10369-10378. DOI: 10.1021/acs.est.7b02667. http://pubs.acs.org/doi/10.1021/acs.est.7b02667 Wilson, J.L., 2017, Phytoforensics—Using trees to find contamination: U.S. Geological Survey Fact Sheet 2017–3076, 2 p., https://doi.org/10.3133/fs20173076.	Tree sampling data are not available at this time. For the VI PHA, ATSDR is evaluating currently available data.

Document Tracked Comments		
5	Section 3.2.2, specific tasks main bullet 2, "Conduct exploratory data analysis, including the creation of GIS maps of the base, to determine areas where buildings with "high potential VI risk," "medium potential VI risk," and "low potential VI risk" are located; also, create labels (i.e., Area 1, Area 2, etc.) encompassing buildings in the same area." How will you break out "high" "medium" and "low". Is this based on numerical score (if so, what is the score) or percentages (i.e., "high" = top 25% of buildings) I think you need to do something so all 1500 buildings are not "high potential VI Risk"	As stated previously, ATSDR will use technical expertise and professional judgement to evaluate the contaminant scores (compiled as *numerical scores* from Tables 3B–7B, Appendix B) and building factors (compiled as *text* from Table 2B, Appendix B) found in Table 8B, Appendix B, when determining each building's placement in one of the VI risk categories. ATSDR does not expect 1,500 buildings to fall into the "high potential VI risk" category, and will work with Camp Lejeune to address that happenstance if it occurs.
3	Section 3.3, paragraph 1, "ATSDR's Prioritization Scheme will assist the agency in designating buildings on the base as "high potential VI risk," "medium potential VI risk," "low potential VI risk," "no apparent VI risk," and "unknown VI risk." Is the risk classification scheme defined?	ATSDR added a description of the VI risk categories to section 3.1, paragraph 5.
5	Section 3.3.1, paragraph 3, "ATSDR will use these AFs to estimate building-specific indoor air concentrations for periods when groundwater contaminant concentrations are available for these buildings." I may have missed it, but somewhere there needs to be a discussion of the uncertainties in the estimated indoor air concentrations.	In Section 4 (Limitations), main bullet 12, ATSDR discusses uncertainty in the historical indoor air estimates.
5	Section 3.3.1, specific tasks main bullet 2, "Gather building-specific characteristics (i.e., building heights, construction, and air exchange rates) for those buildings with measured groundwater data allowing for the calculation of a 95% UCL value and those buildings with simulated groundwater data." I don't understand this bullet. Do you mean gather building-specific characteristics for J&E modeling? You don't need this information to calculate a 95%UCL.	Building characteristics, like building height, are needed to derive groundwater-to-air non-residential attenuation factors (see Appendix C). To avoid confusion, ATSDR revised the sentence to state, "…for those buildings with measured shallow groundwater data that are representative over space and time, and those buildings with simulated groundwater data."

Document Tracked Comments		
3	Section 3.3.1, specific tasks main bullet 2, "Gather building-specific characteristics (i.e., building heights, construction, and air exchange rates) for those buildings with measured groundwater data allowing for the calculation of a 95% UCL value and those buildings with simulated groundwater data." What is the purpose of these data?	Building characteristics, like building height, are needed to derive groundwater-to-air non-residential attenuation factors (see Appendix C).
5	Section 3.3.1, main bullet 3, "…estimate building-specific indoor air contaminant concentrations for available time periods (i.e., 1980s, 1990s, 2000–2007, and 2008–2013) using the AF_{USEPA} as follows…" For all the IA concentration estimates... Need to include Henry's law coefficient in the equation (C_ia = AF x HLC x C_gw)	Thank you for catching the missing components of the equations found in Section 3.3.1. ATSDR corrected this oversight in the work plan.
1	Section 3.3.1, specific tasks main bullet 4, "…with simulated shallow groundwater data, estimate building-specific indoor air contaminant concentrations for available time periods using the AF_{USEPA} as follows…" See my comment above in section 3.1.4. The AF_{USEPA} for groundwater of 0.001 is for groundwater that is greater than 5 ft below the foundation. This might not be an appropriate AF in areas with shallow (less than 5 ft below foundation) groundwater.	ATSDR agrees that the attenuation factors may need to vary when depths to groundwater are less than 5 ft, and for those areas, the agency will assume no attenuation is occurring. The agency added a bullet to Section 3.3.1 stating, • "For buildings with an average depth to groundwater of <5 ft, change the groundwater attenuation factors for the above estimated indoor air contaminant calculations to assume no attenuation is occurring (i.e., attenuation factor equals 1)."
3	Section 3.3.1, specific tasks main bullet 8, "For buildings with indoor air measurements, determine how well the estimated indoor air concentrations matched actual indoor air measurements, most likely using a Kendall's Tau rank correlation coefficient." Critical to address potential temporal influences, i.e., will data used to estimate indoor air concentrations and measured indoor air concentrations be near concurrent.	Yes, ATSDR will use near concurrent data for this effort.

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5	Section 3.3.1, specific tasks main bullet 8, "For buildings with indoor air measurements, determine how well the estimated indoor air concentrations matched actual indoor air measurements, most likely using a Kendall's Tau rank correlation coefficient." Don't you want to include a similar assessment using soil gas data?	ATSDR is using historical shallow groundwater data to estimate indoor air contaminant concentrations. The agency describes in bullet 8 how it will check if the estimated indoor air levels are similar to actual measured indoor air levels because for some buildings, both measured and estimated levels are available. Unlike with historical groundwater data, there are very limited historical soil gas data available to assist with estimating historical indoor air exposures. Because there are so few samples, ATSDR cannot estimate past indoor air exposures from these soil gas data.
1	Section 3.3.1, specific tasks main bullet 9, "Use the J&E model to estimate reasonable ranges of AFs based on a series of site-specific scenarios..." I think this is a great approach. I would suggest doing a Monte Carlo simulation, and the site-specific knowledge of uncertainty should be used to develop parameter ensembles to be used in the Monte Carlo simulation.	ATSDR does not have the resources at this time to implement a stochastic approach in running the J&E model. A bounding approach that incorporates the site-specific knowledge and uncertainties in the parameters will be used instead.
5	Section 3.3.1, specific tasks main bullet 9, sub-bullet 1 "The ranges will be used to explore the upper and lower bounds of vapor intrusion using a series of building, soil, and groundwater characteristics. ATSDR can compare the measured data to simulated data to explore the uncertainty in the measured data and validate the model. ATSDR can also explore comparing the AF ranges from the J&E model to the USEPA, NESDI, and calculated AFs that will be used to estimate past indoor air concentrations." Not a lot of detail here. Not sure what you plan to do. OK with this, just suggest you add more detail. Also, consider refined assessment of capillary fringe (see Shen et al., 2013. Environmental Engineering Science). simple homgeneous capillary fringe model used by USEPA likely under predicts impact of capillary fringe)	ATSDR will consider the information on surface capping and capillary fringe discussed in the Shen article. Soil type will be determined based on site-specific soil boring data and soil survey maps of the area from USDA.
3	Section 3.3.2, specific tasks main bullet 2, sub-bullet 1, "Summarize building-specific information previously compiled in the VI database and maps, particularly information from Sections 3.1.3 and 3.2.2. This information includes: …." You may wish to also include basic information on the building such as size and building foundation.	ATSDR updated Section 3.3.2, specific tasks main bullet 2, sub-bullet 4 to state, "Work with MCB Camp Lejeune to verify current building occupancy, determine whether occupancy changed over time, confirm building use over time, and gather building floor plan, size, condition, and foundation information."

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5	Section 3.3.2, specific tasks main bullet 3, "Using the building-specific conceptual models, determine the public health implications of potential current and historical exposures to indoor air contamination that may have resulted from vapor intrusion into buildings on the base." Looking at the ATSDR guidance it seems like potential actions from the public health assessment focus on current/future exposures. So, it is not clear to me how historical exposures will be evaluated. I think it is important to discuss the uncertainties of the analysis here too.	ATSDR agrees that the agency's recommendations to protect public health tend to focus mostly on current and future exposures. However, identifying past exposures is an integral part of the process, and is discussed in ATSDR's 2005 guidance manual [ATSDR 2005], which states (underline emphasis added) • **Section 2.1.3:** The public health assessment is used by ATSDR to identify possible harmful exposures and to recommend actions needed to protect public health…It considers <u>past exposures</u> in addition to <u>current and potential future exposures</u>. • **Section 6.1:** <u>Past, current, and future exposure conditions</u> need to be considered because the elements of an exposure pathway typically change with time. ATSDR will evaluate historical exposure levels to determine whether estimated indoor air levels in the past were potentially at levels that could harm health. Uncertainties are discussed in Section 4 (Limitations).
3	Section 4, main bullet 5, "Further, some of the older historical data were collected and analyzed using procedures that have since been revised; therefore, some of the older sampling data might not be as accurate or precise as more recent results." Critically important.	ATSDR agrees.
5	Section 4, main bullet 6, "In its VI evaluation, ATSDR will attempt to use the VI database to distinguish between the contributions of VI contaminants and those of indoor and outdoor sources." Can the data be evaluated to assess background indoor concentrations for some of the target VOCs? For example, what is the range of concentrations of benzene and xylene in indoor air in areas where benzene and xylene are not detected in groundwater or soil gas?	ATSDR can assess residential background indoor air concentrations using a USEPA report, *Background indoor air concentrations of volatile organic compounds in North American residences (1990–2005): a compilation of statistics for assessing vapor intrusion* [USEPA 2011]. MSC Camp Lejeune is currently compiling information on potential indoor sources for specific buildings, which ATSDR will consider in its evaluation.

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5	Section 4, main bullet 8, "ATSDR will use Appendix B of its VI guidance [ATSDR 2016] and Holton [2013] as a guide to consider factors affecting temporal variability." Note that much of the variability reported in Holton 2013 is a result of a drainline that connects the sub-slab to a sewer with high levels of TCE. The temporal variability after this drain line was closed should be used for the ATSDR assessment of temporal variability.	Because vapor intrusion tends to have active and dormant phases, ATSDR will use concepts similar to those in Holton [2013] to qualitatively consider the likelihood that indoor air samples would capture an exceedance of a CV. The Holton study is an example and ATSDR will discuss how deviations from that example might shift the statistics. Preferential paths were discovered in both residences used by USEPA to study temporal variability, so inference is necessary.
3	Section 4, main bullet 9, "Vapor intrusion can be influenced by underground utilities (i.e., potential pathways) which are widespread at the base." Recommend additional information on how utilities can affect indoor air quality. There are several recent publications and conference presentations (e.g., see AEHS San Diego 2017 and 2018 conferences.)	Thank you for the additional references regarding utilities and indoor air quality. ATSDR will consider these references as we draft the VI PHA.
3	Section 4, main bullet 12, "Although the agency is anticipating that some buildings will have available measured indoor air data for comparison to the estimated concentrations (e.g., determine the relationship between the estimated and measured concentrations), this may not be the case." Consider whether calibration is possible.	The agency has not identified another method to calibrate the estimated concentrations.
1	Appendix A, Figure 1A: Camp Lejeune's Vapor Intrusion Evaluation Approach (page 1 of 3) Last text block wording is odd. Might be changed to "identifying buildings that are located within 100 ft…" or "identifying which buildings are located within 100 ft…"	The source of this figure is a CH2M document released in 2009; ATSDR therefore cannot modify the figure.
5	Appendix B, Table 1B. Chemicals for Vapor Intrusion Assessment Identify which of these chemicals has been detected at Camp Lejeune. Also, show the CV and VICV for the chemicals.	ATSDR added Tables 9B and 10B, Appendix B, to the work plan that provides the CVs and VICVs being used to screen the Camp Lejeune data. The VI PHA itself will identify the specific chemicals that were detected, and whether they were above CVs and/or VICVs.

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1	Appendix B, Table 3B. Frequency of Results Factor Analysis Chart Why is 8 used?	As stated previously in response to another comment, ATSDR's exposure point concentration workgroup simulated confidence limits coverage for more typical distributional assumptions and recommended a minimum of 8 samples, with at least 4 of those samples having detected results and at least 20% of the samples having detected results, as the floor for sample size to have a reasonable frequency of the upper confidence level (UCL) being within 10% of the true population mean. The agency expects guidance for estimating exposure point concentrations, which includes these recommendations for minimum sample size, to be released soon. This information was added as a footnote to Table 3B, Appendix B. Note, a similar analysis was performed for ProUCL that states "Just like other government documents (e.g., U.S. EPA 2009), various versions of ProUCL (2007, 2009, 2011, 2013, 2016) also make some rule-of thumb type suggestions (e.g., minimum sample size requirement of 8-10) based upon professional judgment and experience of the developers." [USEPA 2015a]
5	Appendix B, Table 5B. Shallow Groundwater Factor Analysis Chart, "…highest average contaminant concentration exceeds its long-term VICV" Add footnote that if average concentration cannot be calculated, the maximum concentration should be used.	ATSDR agrees and added the suggested footnote to this table.
5	Appendix B, Table 5B. Shallow Groundwater Factor Analysis Chart, "…highest 95% UCL contaminant concentration exceeds its long-term VICV…" Add footnote that if 95%UCL cannot be calculated, the maximum concentration should be used.	ATSDR agrees and added the suggested footnote to this table as well as Tables 6B and 7B, Appendix B.
3	Appendix B, Table 6B. Soil Gas Factor Analysis Chart, "Maximum contaminant concentration exceeds its short-term VICV and highest 95% UCL contaminant concentration exceeds its long-term VICV during any time period" Same as description for 1?	No, the description is not the same for the 2-point and 1-point text. For the 2-point text, both conditions are met hence the underlined word "and" in the sentence. For the 1-point text, only one of the conditions is met hence the underlined work "or" in the text.

Document Tracked Comments		
5	Appendix B, Table 6B. Soil Gas Factor Analysis Chart, "Choose for all other situations" including CV not calculable.	Only contaminants with CVs will be considered within the Prioritization Scheme; therefore, this requested addition to Table 6B, Appendix B, was not made. To clarify, however, ATSDR added to the last bullet in Section 3.1.5 this text, "Note, these 30 contaminants with no CVs will be reviewed outside the Prioritization Scheme; if any of these contaminants are found to be a potential VI risk, the buildings within 100 ft will be included as part of the building-specific public health evaluations in Section 3.3.2."
5	Appendix B, Table 6B. Soil Gas Factor Analysis Chart, "There are no shallow groundwater data" Is this a typo? Should this be soil gas?	Yes, the table should state "soil gas"; this error was corrected in the work plan.
5	Appendix C, last sentence, "Note, using the 0.0006 calculated non-res AF_{ss} for commercial buildings…" Typo? - should be 0.006?	Yes, the correct value is 0.006 and this error was corrected in the work plan.

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[ATSDR] Agency for Toxic Substances and Disease Registry. 2016. Evaluating vapor intrusion pathways, guidance for ATSDR's Division of Community Health Investigations. Atlanta: US Department of Health and Human Services. Available at: https://www.atsdr.cdc.gov/docs/svi_guidance_508.pdf

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[USEPA] US Environmental Protection Agency. 2015a. ProUCL version 5.1 technical guide – statistical software for environmental applications for data sets with and without nondetect observations. Prepared for USEPA. by Anita Singh, PhD (Lockheed Martin/SERAS) and Ashok K. Singh, PhD (University of Nevada). EPA/600/R-07/041. Washington, DC: U.S. Environmental Protection Agency.

[USEPA] US Environmental Protection Agency. 2015b. Technical guide for addressing petroleum vapor intrusion at leaking underground storage tank sites. EPA 510-R-15-001. Washington, DC: US Environmental Protection Agency, Office of Underground Storage Tanks. June 2015.

[USEPA] US Environmental Protection Agency. 2017. Regional screening level (RSL) residential air supporting table November 2017. Washington, DC: US Environmental Protection Agency.

Appendix E. Curriculum Vitae for each External Peer Reviewer

This appendix provides the curriculum vitae of each external peer reviewer of the work plan. Note that the order of the curriculum vitae does not align with the external peer reviewer numbers provided in Appendix D. The six reviewers are:

A. Gordon Dean

B. Richard B. Kapuscinski

C. Robert Ettinger

D. Nadine Weinberg

E. Jordan Wilson

F. Ian Hers

A. Gordon Dean

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SUMMARY

Mr. Dean has more than 35 years of assessment and remedial design experience, including 29 years in the private sector. He also has over six years experience with the Florida Department of Environmental Protection (FDEP) where he authored guidelines for Initial Remedial Actions and soil cleanup at petroleum-contaminated sites. He is a registered Professional Engineer in Florida and several other states. He has designed remedial systems for ground water recovery and treatment, soil treatment, contaminant plume capture and control, and other remediation processes. He was the Program Manager for six contracts with FDEP and also provided technical oversight and support of remedial design and other engineering functions for all offices of a nationwide consulting firm. He is a specialist in compliance with federal, State of Florida, and local regulations, and widely experienced in health and safety and quality assurance/quality control issues.

WORK EXPERIENCE:

Vice President/President – Advanced Environmental Technologies, LLC

November 2013 to present – Vice President of one of the largest petroleum cleanup contractors in Florida. Also served as President for two years at the request of the owner. Provides senior engineering support for remedial actions and consulting services for clients purchasing environmentally distressed properties nationwide.

President – Restoration Associates, Inc.

November 2009 to present – Principal of a startup engineering company specializing in petroleum and hazardous waste remediation.

Director of Business Development – Fortis Environmental Group, LLC and Tri-Con, Inc.

June 2008 to November 2009 – responsible for marketing and business development for two small, woman-owned businesses. Assumed senior engineering duties after lead engineer left company. Designed several remediation systems using large diameter augers and in-situ chemical oxidation.

Vice President, Engineering - WRS Infrastructure & Environment, Inc. (formerly Westinghouse Remediation Services, Inc.)

July 1997 to April 2008 - Continued duties outlined below while expanding involvement in nationwide business development in soil and groundwater remediation and other environmental services. Participated in the procurement of over $750 million in governmental and private contracts. Contract Manager for WRS's Team 5 contract providing 24 technical and administrative personnel to the FDEP as well as oversight of the FDEP Equipment Management contract and three land acquisition contracts with FDEP. Provided review and professional certification of Phase I Environmental Site Assessments and other similar assessments on almost 2% of Florida's total land area.

Design projects included a two mile extension of a potable water pipeline in Concord, North Carolina; a groundwater treatment system at the same site; a water polishing system in Hatboro, Pennsylvania; and pesticide remediation pilot testing in Belle Glade, Florida.

Technical Group Manager - Westinghouse Remediation Services, Inc.
May 1993 to July 1997 - Responsible for the supervision of all engineers and scientists in four Florida offices. Design engineer/project manager for the Fairbanks Disposal Pit CERCLA/RCRA site, a site with four aquifers contaminated with chlorinated solvents and a remediation budget of over $50 million. Contract manager for the FDEP Hazardous Waste and Drycleaning Solvent Cleanup Program, the FDEP Land Acquisition Environmental Audit Program, the FDEP Petroleum Cleanup Program, the FDOT Statewide Environmental Services Program, and the FCX-OU1 CERCLA site.

General Manager - PDG Environmental, Inc.
January 1993 to May 1993 - Continued job duties described below following purchase of IRC Environmental by PDG Environmental. Facilitated transfer of statewide petroleum cleanup contract to PDG Environmental.

Vice President - IRC Environmental, Inc./Cherokee Groundwater Consultants, Inc.
March 1990 to January 1993 - Opened a venture office and built the office to 10 people. Prepared, reviewed, and sealed Contamination Assessment Reports, Remedial Action Plans, and closure permits for RCRA and petroleum sites as Engineering and Technical Director. Designed over 50 groundwater recovery and treatment and/or soil treatment systems, including: recovery wells, high volume trench recovery, air strippers, activated carbon adsorption, catalytic oxidation, free product recovery, soil biodegradation, in-situ intrinsic remediation, and horizontal and vertical vacuum extraction. Procured and managed a $24 million statewide petroleum cleanup contract.

Professional Engineer II - Florida Department of Environmental Regulation
August 1989 to March 1990 - Designed, reviewed and sealed Remedial Designs and Remedial Action Plans for CERCLA, RCRA, and petroleum waste sites. Co-author of Chapter 17-770, Florida Administrative Code (Petroleum Cleanup Rule) and the NPDES Statewide Petroleum General Permit.

Engineer IV - Florida Department of Environmental Regulation
June 1987 to July 1989 - Designed and reviewed Remedial Investigations, Feasibility Studies, Remedial Designs, and Remedial Action Plans for CERCLA, RCRA, and petroleum waste sites. Authored guidelines for initial remedial actions, soil and groundwater cleanup, and Remedial Action Plan preparation.

Engineer II - Florida Department of Environmental Regulation
May 1986 to May 1987 - Supervised three on-scene coordinators. Provided engineering review of Contamination Assessment Reports, Remedial Action Plans, Remedial Investigations, Feasibility Studies, and Remedial Designs for CERCLA, other hazardous waste, and petroleum contamination sites.

Engineer I - Florida Department of Environmental Regulation
October 1983 to April 1986 - Provided field engineering supervision of contractors as an on-scene coordinator (OSC) at over 30 CERCLA and other hazardous waste sites. Also provided engineering review of Contamination Assessment Reports and Remedial Action Plans and was the Department's only OSC for the first year.

PROJECT EXPERIENCE

Program Manager, six FDEP contracts, Statewide Florida. These contracts were the Petroleum Cleanup Program Team 5, Petroleum Cleanup Program Equipment Management, Drycleaning Solvent Cleanup Program, Division of State Lands Environmental Site Assessments, Division of State Lands Baseline Documentation, and Division of State Lands Conservation Easement Monitoring.

Sr. Project Engineer for the FDEP Division of State Lands ESA contract, Statewide Florida. In this role, Mr. Dean supervised, signed, and sealed over 4,000 environmental site assessments covering approximately 2% of the total land area of the State of Florida. He was also the design engineer for feasibility studies and pilot testing for toxaphene remediation at the Belle Glade Airport site.

Project Manager/Design Engineer for the Fairbanks Disposal Pit, Gainesville, Florida. This FDOT site had contaminant impacts to four aquifers. The site was regulated by CERCLA/ RCRA under an Administrative Consent Order. Mr. Dean designed Corrective Action Plans for all four aquifers, including the use of innovative, high-volume horizontal wells for the surficial aquifer.

Design Engineer, USEPA Region IV Emergency Response Contract. Mr. Dean served as the design engineer for a 2-mile long potable water pipeline. The pipeline provides potable water to families impacted by the Ram Leather Superfund Site in Charlotte, North Carolina. The work was funded by EPA, and connects an existing potable water pipeline from the City of Concord to four houses whose wells have been impacted by chlorinated solvents. The pipeline crosses a county line, the boundary between two DOT districts, and a railroad. Approval of the design was coordinated between all parties.

Sr. Project Engineer at sites throughout Florida. Mr. Dean designed groundwater and soil treatment systems for over 150 petroleum and 20 hazardous waste sites in Florida. The treatment systems have included pump and treat, groundwater sparging, soil vapor extraction, carbon adsorption, and free product recovery.

Sr. Project Engineer for Florida DOT, Chadbourne Construction Facility in Pensacola, Florida. Mr. Dean designed a treatment system for remediation of chlorinated solvents. The system consisted of soil vapor extraction, groundwater recovery from four recovery wells and air stripping of the recovered water. This was the first chlorinated solvent site in Florida to obtain a Site Rehabilitation Completion Order.

Wm. Gordon Dean, PE

Major author of the Water Quality Impact Evaluation Manual (guidance for Part 2, Chapter 20 of the FDOT PD&E Manual). In addition to completing portions of the manual, Mr. Dean also presented the associated course numerous times, training over 200 FDOT employees.

Sr. Project Engineer for the Nanak Cleaners Site in Winter Park, Florida. This project was completed under the Drycleaning Solvent Cleanup Program administered by FDEP. Mr. Dean designed an air sparging and horizontal soil vapor extraction system.

Sr. Project Engineer at the Town and Country Cleaners Site in Orange Park, Florida. This project was completed under the Hazardous Waste Cleanup Program administered by FDEP. Mr. Dean designed an air sparging and horizontal soil vapor extraction system.

Sr. Engineer and Technical Support for seven Florida DOT contracts. Services provided by Mr. Dean included contamination assessment, Level I and II assessments, impact to construction assessment, initial remedial action, remedial design, underground storage tank (UST) removal and closure, supervision of treatment system installation, O&M, permitting, and community relations.

On-Scene Coordinator at sites throughout Florida. Mr. Dean served as the on-scene coordinator at over 30 CERCLA and hazardous waste sites throughout the State.

Design Engineer at the Florida DOT Goldenrod Road Project in Orlando, Florida. Mr. Dean designed a groundwater contamination plume capture system which involved counter pumping and water table flooding to create a series of hydraulic divides to complement the dewatering system effect and overcome its hydraulic loading characteristics. This system allowed construction to proceed with little or no downtime, and is believed to be the first such application in the United States.

Project Engineer/Manager at sites throughout Florida for Florida DOT. Mr. Dean designed and supervised installation of over 30 aboveground fuel storage and dispensing systems for various FDOT maintenance yards.

Project Coordinator/Engineer at the Brown Wood Preserving Site in Live Oak, Florida. Mr. Dean coordinated and reviewed plans for remediation activities at the site. This project was one of the only known successful bioremediation clean-closure sites in the state at that time.

EDUCATION:

University of Florida, College of Chemical Engineering, September 1979 to April 1983
    Received Bachelor of Science in Chemical Engineering on April 30, 1983

Florida State University, College of Chemistry, September 1977 to August 1979
    National Merit Scholar

CURRENT PROFESSIONAL ENGINEERING REGISTRATIONS

STATE	PE LICENSE No.	ISSUED	EXPIRES
Florida (Original Certification)	40950	2/9/89	2/28/2019
Alabama	18407	6/21/91	12/31/2019
Georgia	19403	7/16/91	12/31/2018
Louisiana	30895	9/23/03	3/31/2018
Mississippi	16100	10/31/03	12/31/2018
North Carolina	25288	10/20/99	12/31/2018

National Council of Examiners of Engineers and Surveyors No. 9661, issued December 17, 1990
Designated by NCEES as a Model Law Engineer.

PUBLICATIONS

Water Quality Impact Evaluation; Florida Department of Transportation Training Course No. BT-05-009, June 1994

Guidance Manual for Review of Petroleum Remedial Action Plans; Florida Department of Environmental Regulation, October 1989

Guidelines for Assessment and Remediation of Petroleum Contaminated Soils; Florida Department of Environmental Regulation, 1989

Initial Remedial Action, A Quick and Dirty Response; Petrogram, January 1989

PRESENTATIONS

Florida Remediation Conference, December 2017
Does PlumeStop Work in Florida?
Florida Remediation Conference, October 2009
Innovative Uses of Large Diameter Augers in Site Remediation
NISTM Florida and National Conferences, 2008 to present
Basics of Site Assessment and Remediation
NISTM Aboveground Storage Tank Conference, September 2008
Basics of AST Site Remediation
1st Annual Underground Storage Tank Conference, December 2004
What Owners Should Know About Communicating with Their Cleanup Contractors
Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, May 2004
Remediation of Toxaphene-Contaminated Soils Using Tilling and Quick Lime
14th Annual West Coast Conference on Soils, Sediments, and Water, March 2004
Ex-Situ Treatment of Dense Non-Aqueous Phase Liquids Using Calcium Oxide (Quick Lime)
National Public Land Acquisition and Management Partnership Conference, December 2003
Due Diligence in the Land Acquisition Process
19th Annual International Conference on Soils, Sediments, and Water, October 2003
Ex-Situ Treatment of Dense Non-Aqueous Phase Liquids Using Calcium Oxide (Quick Lime)
Florida Remediation Conference, November 2002
Ex-Situ Treatment of DNAPLs Using Quick Lime
New Approaches to Modeling Flow and Fate and Transport in Karst Settings, November 2001
Assessment and Remediation of the Fairbanks Disposal Pit Site
Approaches to Attenuation and Remediation of Contaminants in Karstic Settings, November 2000
Chlorinated Solvent Contamination in a Karstic Environment
FDOT Environmental Management Office Conference, September 2000
Overview of Remediation Technologies
FDEP Drycleaning Solvent Cleanup Program Contractor's Workshop, September 1999

Remediation of the Town and Country Drycleaners Site

Annual EPA/FDEP RCRA Workshop, August 1999

Fairbanks Disposal Pit Site Panel Discussion

FDEP Thirteenth Annual Storage Tanks/Cleanup Program Meeting, May 1999

Davie Boulevard Case Study

Transportation Research Board Mid-Year Workshop, July 1999

Use of Recycled Materials in Transportation Systems

Fairbanks Disposal Pit Case Study

Transportation Research Board Mid-Year Workshop, July 1998

Use of Recycled Materials in Transportation Systems

First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, May 1998

Chlorinated Solvent Groundwater Remediation at the Fairbanks Disposal Pit

Superfund XVII Conference, October 1996

Performance of Horizontal Recovery Trenches at the Fairbanks Disposal Pit Site

FDOT Environmental Management Office Conference, October 1996

Fairbanks Disposal Pit Site Panel Discussion

Florida Remediation Conference, November 2002

Ex-Situ Treatment of DNAPLs using Quick Lime

Florida Remediation Conference, November 1995

Is Pump and Treat Dead or Just Misunderstood

FDOT Environmental Management Workshop, April 1995

Geophysical Surveys and their Interpretation

FDOT Environmental Management Workshop, April 1995

To Remediate or Not to Remediate

National Research Council, Transportation Research Board Conference, January 1995

Plume Capture During Construction

FDOT Training Course No. BT-05-0009, June 1994

Water Quality Impact Evaluation

FDOT Environmental Management Workshop, May 1994

Contamination Dewatering with Plume Capture

FDOT Environmental Management Workshop, May 1994

Environmental Laboratory Data Interpretation

Florida Environmental Expo, October 1993

Expedited Remedial Action at the I-595 and Davie Blvd. Site: A Case Study

SPECTRA Engineering and Research Conference, July 1992

Technical Requirements for Remedial Action, Monitoring Only, and No Further Action Plans

FDEP Storage Tanks Program Annual Conference, June 1992

Applied Site Remediation Technologies

FDEP Storage Tanks Program Annual Conference, May 1991

Site Remediation Technology

University of Massachusetts Fourth Annual Conference on Petroleum Contaminated Soils, September 1989

State of Florida Policy on Petroleum Contaminated Soils

HMCRI 1989 Hazardous Waste and Hazardous Materials Conference, April 1989

State of Florida Policy on Petroleum Contaminated Soils

EPA National "Making It Work" Petroleum Workshop, November 1988

Four presentations on Florida's remediation policies

Wm. Gordon Dean, PE

TRAINING

AEHS	14th Annual West Coast Conference on Soils, Sediments, and Water, March 2004
ASCE	Design and Construction of Soil Liners and Covers, May 1994
Battelle	Remediation of Chlorinated and Recalcitrant Compounds, May 1998
Battelle	Remediation of Chlorinated and Recalcitrant Compounds, May 2004
CCG	Claims Recognition, Analysis, and Resolution Seminar, May 1987
CCG	Critical Path Method Scheduling, May 1987
Cherokee	OSHA 1910.120 Site Supervisor Course, July 1990
Cherokee	OSHA 1910.120 Trainer Course, January 1991
EPA	Hazard Evaluation and Environmental Assessment, August 1985 (EPA 165.6)
EPA	Incident Mitigation and Treatment Methods, March 1984 (EPA 165.3)
EPA	National Invitational Workshop on Vacuum Extraction, June 1989
EPA	National "Making It Work" Petroleum Workshop, November 1988
EPA	Network Design for External Tank Monitoring of Underground Storage Tanks, August 1988
EPA	Personnel Protection and Safety, February 1984 (EPA 165.2)
EPA	Response Safety Decision Making Workshop, June 1984 (EPA 165.8)
EPA	Site Safety Considerations, Personnel Protection, and Fundamental First Aid Training Program, December 1983
FDEP	Drycleaning Solvent Cleanup Program Contractor's Workshops, September 1997, September 1998, September 1999
FDEP	Effective Speaking, March 1989
FDEP	EPA/FDEP Annual RCRA Workshops, August 1999, November 2000, August 2001
FDEP	Getting It Right the First Time - Answers to Petroleum Cleanup, November 1990
FDEP	Local Governments Annual Meeting, April 1988
FDEP	National Public Land Acquisition and Management Partnership Conference, December 2003, November 2005
FDEP	Pollutant Storage Tank Annual Meetings, June 1987, June 1988, June 1989, May 1991, June 1992, May 1999, June 2000, September 2001, August 2002, July 2003, July 2004, June 2006
FDMS	Office of Supplier Diversity – One Florida Roundtable, July 2001
FDOT	Environmental Management Office Workshops, May 1994, April 1995, October 1996, September 1998, September 2000
FEE	Florida Environmental Expo, October 1993
Florida Chamber	14th Annual Environmental Permitting Summer School, July 2000
Florida Specifier	Florida Remediation Conferences, November 1995, November 2002, November 2004, December 2016, December 2017
HC	Approaches to Attenuation and Remediation in Karstic Settings, November 2000
HC	New Approaches to Modeling Flow and Fate and Transport in Karst Settings, November, 2001
HMCRI	1989 Hazardous Waste and Hazardous Materials Conference, April 1989
HWMA	Superfund XVII Conference, October 1996
NISTM	1st Annual Underground Storage Tank Conference, December 2004
NRC	Transportation Research Board Annual Conference, January 1995
NSC	Hazardous Waste Supervisors Development Program, August 1993
NWWA	Corrective Action for Containing and Controlling Ground Water Contamination, February 1985
NWWA	Design, Installation, and Sampling of Ground Water Monitoring Wells, April 1984
NWWA	Ground Water Treatment Technology, June 1988

NWWA	Ground Water and Unsaturated Zone Monitoring and Sampling, October 1986
NWWA	Petroleum Hydrocarbons and Organic Chemicals in Groundwater, November 1984
NWWA	Petroleum Hydrocarbons and Organic Chemicals in Groundwater, November 1990
NWWA	Third National Outdoor Action Conference, May 1989
TRB	Mid-Year Workshops, July 1998, July 1999, July 2001
TRB	79th Annual Meeting, January 2000
U. Mass.	Environmental and Public Health Effects of Soils Contaminated with Petroleum Products, September 1987
U. Mass.	Fourth Annual Conference on Petroleum Contaminated Soils, September 1989
U. Mass.	19th International Conference on Soils, Sediments, and Water, October 2003
USACE	Construction Quality Management for Contractors, April 2004

Acronyms:

AEHS	Association for Environmental Health and Sciences
ASCE	American Society of Civil Engineers
CCG	Construction Consulting Group, Inc.
Cherokee	Cherokee Groundwater Consultants, Inc.
EPA	United States Environmental Protection Agency
FDEP	Florida Department of Environmental Protection (formerly Florida Department of Environmental Regulation)
FDOT	Florida Department of Transportation
FEE	Florida Environmental Expo
HC	The Hydrogeology Consortium
HMCRI	Hazardous Materials Control Research Institute
HWMA	Hazardous Waste Management Association
NISTM	National Institute of Storage Tank Management
NRC	National Research Council
NSC	National Safety Council
NWWA	National Water Well Association
TRB	Transportation Research Board
U. Mass.	University of Massachusetts
USACE	United States Army Corps of Engineers

B. Richard B. Kapuscinski

RICHARD B. KAPUSCINSKI, PhD, PE

(703) 305-7411 (EPA Office) Kapuscinski.Rich@epa.gov

Professional Experience

- Over thirty years of progressively responsible, professional experience as an environmental engineer; licensed as a Professional Engineer in Virginia
- Advised and guided managers, executives, and attorneys regarding public health and environmental protection (e.g., chemical risk assessment, groundwater and soil remediation, vapor intrusion) and regulatory compliance; applied science to policy and program development by regulatory agencies and regulated companies
- Conceived and prepared technical reports, ranging from letter reports and briefing papers to multi-volume documents
- Provided expert testimony in adjudicatory and administrative hearings and made presentations at national symposia and to sponsoring organizations
- Independently planned, conducted, coordinated, and directed work and assembled and supervised multi-disciplinary teams on multiple concurrent projects to ensure that organizational objectives were met and that high scientific and engineering standards were attained

Employment History

- Environmental Engineer, U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation, Arlington, VA (August 2009 – now)
- Senior Manager, ENVIRON International Corporation, Princeton, NJ (Jan. 2004 – August 2009)
- Consulting Engineer, self-employed, Springfield, VA (Jan. 2003 - Jan. 2004)
- Operations Manager and Principal Engineer, GeoTrans, Inc., Sterling, VA (Oct. 2001 - Jan. 2003)
- Operations Manager and Principal Engineer, MACTEC, Inc., Fairfax, VA (Feb. 1997 - Oct. 2001)
- Senior Associate, Manager, or Senior Manager (progressively), ENVIRON International Corporation, Arlington, VA (Jan. 1988 - Feb. 1997)
- Assistant Professor of Civil Engineering, University of Michigan, Ann Arbor, MI (Sept. 1982 - Dec. 1987)
- Assistant Professor of Civil Engineering, University of Vermont, Burlington, VT (Sept. 1980 - Aug. 1982)

Education

- PhD, Engineering (Environmental), Harvard University, 1980
- MS, Engineering (Environmental), Harvard University, 1977
- BS (with distinction), Civil and Environmental Engineering, Cornell University, 1975

Registrations & Affiliations

Member, American Society of Civil Engineers and National Groundwater Association

C. Robert Ettinger

Geosyntec
consultants

ROBERT ETTINGER

vapor intrusion pathway analysis
risk-based corrective action
human health risk assessment
design of soil vapor remediation systems

EDUCATION

B.S., Chemical Engineering, Rice University, Houston, Texas, 1986
M.S., Chemical Engineering, University of California, Berkeley, 1989

CAREER SUMMARY

Mr. Ettinger is an environmental specialist with over twenty-five years of experience, including research, development and direct technical support to gasoline retail and distribution, petroleum pipeline, petrochemical facilities, manufacturing locations, dry cleaner operations, and waste sites. Much of Mr. Ettinger's work has focused on fate and transport of contaminants in the unsaturated zone including soil vapor extraction system design, vapor emission estimation, and subsurface methane and contaminant vapor migration to indoor air. He is also particularly experienced in human health risk assessment, litigation support, design and implementation of groundwater and soil vapor remediation systems, regulatory negotiation, and risk-based strategy development for environmental liability and business management.

Mr. Ettinger is co-author of the Johnson and Ettinger (1991) algorithm for evaluating subsurface contaminant vapor intrusion to indoor air and has conducted field investigations and modeling evaluations on this topic for over a decade. He has published numerous articles on chemical vapor intrusion, environmental fate of volatile chemicals, and design considerations for groundwater and soil vapor extraction systems.

<u>Vapor Intrusion Pathway Analysis</u>

Mr. Ettinger is an internationally recognized expert in the evaluation of the vapor intrusion pathway and has examined this pathway at sites where petroleum products, chlorinated solvents, methane, or other organic compounds are of potential concern. He is the co-author of the most widely-used model to evaluate the vapor migration to indoor air pathway (Johnson and Ettinger, 1991). The Johnson-Ettinger model for assessing vapor intrusion to indoor air is used in guidance documents for USEPA and several state regulatory agencies. Mr. Ettinger has participated in the development of vapor intrusion guidance documents for USEPA, state agencies, and ITRC and the ASTM standard for evaluating the vapor intrusion for property transactions. He has given over three dozen presentations on modeling and/or field investigations at agency meetings, workshops and national conferences.

Relevant vapor intrusion experience for Mr. Ettinger includes:

Robert Ettinger
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Geosyntec consultants

Regional Groundwater Plume Vapor Intrusion Assessment, *Los Angeles County, California*. Developed a strategy to evaluate the potential vapor intrusion pathway from a regional groundwater plume for a USEPA Region 9 CERCLA site. In response to recommendations included in the USEPA five-year review for the site, Geosyntec developed a vapor intrusion assessment strategy consisting of (i) a desktop review of existing environmental data; (ii) prioritization of areas for additional data collection including groundwater, soil vapor, and indoor air sampling; and (iii) evaluation of the supplemental data to recommend follow-up actions.

Vapor Intrusion Assessment, *Sacramento County*, *California*. Developed a strategy and implemented a field investigation to evaluate the potential vapor intrusion pathway for a USEPA Region 9 CERCLA site. USEPA required the assessment of the vapor intrusion pathway for on-site and off-site receptors at an aerospace complex in Sacramento County, California. An investigation consisted of grab samples with real-time analysis for trichloroethene (TCE) to evaluate whether expedited mitigation measures were warranted. Additionally, an indoor air sampling program was implemented to assess potential chronic exposures for on-site buildings and a soil vapor sampling program was prepared to assess the vapor intrusion pathway for off-site locations.

Tier 3 Vapor Intrusion Assessment, *Illinois*. Developed a strategy to streamline Tier 3 assessments for the vapor intrusion pathway under the Illinois EPA Tiered Approach to Corrective Action (TACO) program. Tier 3 soil gas and groundwater remediation objectives for petroleum compounds that would not require institutional controls for future land use were calculated and submitted to IEPA for review and approval.

Vapor Intrusion Pathway Analysis, *Carson, CA.* Developed a strategy to conduct a vapor intrusion pathway evaluation for a residential development constructed at a historical crude oil storage facility. A phased assessment strategy was developed to assess potential safety concerns (i.e., migration of methane to on-site structures), soil vapor investigation, and indoor air sampling. The assessment strategy was developed to identify locations that may warrant immediate or interim actions and also collect data that may be used to distinguish detected compounds from background sources. A multiple linear regression analysis was conducted to evaluate the data and determined that the concentrations of volatile organic compounds detected in indoor air are indistinguishable from background levels.

Vapor Intrusion Pathway Analysis and Mitigation *Santa Clara, CA.* Provided environmental support for vapor intrusion investigation for an electronics manufacturing facility that is part of a Superfund site in the San Francisco South Bay Area. Based on the findings of the indoor air investigation conducted at the site, vapor intrusion mitigation systems were designed and installed for two of the buildings.

Vapor Intrusion Biodegradation Modeling, *Los Angeles, California*. Assessed vapor migration to indoor air from a groundwater source at Region 9 Superfund site, including evaluation of field data, quantification of natural attenuation in the vadose zone and presentation of results to USEPA and DTSC. This is the first site where USEPA and CalEPA/DTSC accepted the use of a biodegradation model to quantitatively evaluate the vapor intrusion pathway.

Vapor Intrusion Pathway Analysis, *Aberdeen, Maryland*. Developed a strategy to conduct a vapor intrusion pathway evaluation for a large site with more than 400 structures. A multi-component site conceptual model was developed for the property and an investigation strategy developed to focus efforts to areas with greater likelihood of significant vapor intrusion concerns.

Vapor Intrusion Expert Witness, *St. Petersburg, Florida*. Provided expert witness support for a vapor intrusion litigation case in St. Petersburg, Florida. A vapor intrusion evaluation was conducted to assess the potential for chlorinated volatile organic chemicals detected in a groundwater to migrate into indoor air for properties in a mixed residential/commercial neighborhood. This work included an assessment of field investigation methods and a forensic evaluation to distinguish the contribution of background sources versus sub-surface contaminants to concentrations measured in indoor air.

Vapor Intrusion Expert Witness, *Santa Rosa, California*. Provided expert witness support and testimony for a vapor intrusion litigation case in Santa Rosa, California. A vapor intrusion evaluation was conducted to assess the potential for chlorinated volatile organic chemicals detected in a groundwater to migrate into indoor air for properties in a residential neighborhood. This work included a forensic evaluation to distinguish the contribution of background sources versus sub-surface contaminants to concentrations measured in indoor air.

Vapor Intrusion Modeling Study, American Petroleum Institute, *Washington, D.C.* A vapor intrusion modeling study, sponsored by API, was conducted to assess the significance of vadose-zone biodegradation in limiting the migration of petroleum hydrocarbon vapors to indoor air. The study findings concluded that natural biodegradation mitigates the vapor intrusion pathway for dissolve petroleum hydrocarbon groundwater plume sites.

Vapor Intrusion Pathway Analysis, *Orange, California*. Conducted an indoor air sampling investigation to evaluate the vapor intrusion pathway for chlorinated and petroleum hydrocarbon compounds for buildings located adjacent to a closed landfill. Results from the indoor air data were reviewed to assess the contributions due to background sources and potential subsurface sources.

Vapor Intrusion Pathway Analysis, *Los Angeles, California*. Conducted a soil gas, sub-slab soil gas and indoor air sampling program for school site impacted by a chlorinated solvent plume. CalEPA/DTSC vapor intrusion guidance was followed in the collection and interpretation of these data. A risk evaluation of the data collected in this study was performed to identify follow-up actions including risk communication and engineering controls evaluation.

Vapor Intrusion Pathway Analysis, *San Diego, California*. Conducted sub-slab soil gas and indoor air sampling program for chlorinated solvent release site at a commercial research and development facility. CalEPA/DTSC vapor intrusion guidance was followed in the collection and interpretation of these data. A risk evaluation of the data collected in this study was performed to identify follow-up actions including risk communication and engineering controls evaluation.

Indoor Air Sampling and Analysis, *Torrance, California*. Conducted indoor air sampling program for chlorinated solvent release site at a commercial building complex. This work was conducted as part of the RCRA Corrective Action program for the site and also was used to assist in property sale. CalEPA/DTSC vapor intrusion guidance was followed in the collection and interpretation of these data. Worked with client and regulatory agency to communicate findings to building occupants.

Vapor Intrusion Mitigation System Modeling, *Los Angeles, California*. Developed a model to evaluate effectiveness of engineering controls to prevent vapor intrusion. This model was approved by the CalEPA/DTSC to develop site-specific corrective action goals for a chlorinated hydrocarbon contaminated site redevelopment.

Risk Based Corrective Action Strategy Development

Mr. Ettinger has directed contaminated site investigation programs and developed risk-based corrective action strategies for sites across the United States. In his previous job, he served as a technical focal point for risk-based corrective action (RBCA) assessments and regulatory negotiations for a major oil company. His responsibilities included site assessment planning, fate and transport modeling, and corrective action strategy development for the preparation of RBCA evaluations at retail, distribution, pipeline, refining, and chemical manufacturing locations. Mr. Ettinger has worked with industry groups and state agencies to incorporate risk-based decision making concepts in the development and revisions to cleanup programs (specifically in TX, LA, and WA) and has performed site evaluations using risk-based approaches in AK, CA, CO, ID, IL, LA, MA, OH, OR, TX, UT, and WA.

Relevant RBCA experience for Mr. Ettinger includes:

Site Remediation Strategy Development, *Arvin, California*. A site investigation and remediation strategy was developed to address contamination due to a condensate pipeline release near a residential community. Data from the initial site investigation and remediation response actions (soil vapor extraction) were reviewed and modifications to the remediation system design were implemented to improve the system efficiency. Post-remediation data were collected to demonstrate to the regulatory agencies that remedial objectives were met and homeowners could re-occupy the home near the release.

Site Remediation Strategy Development, *Orange, California*. A site investigation and remediation strategy was developed to address contamination due to a former wire and cable manufacturing facility. Following a property transaction, the extent of historical contamination from former manufacturing operations at the site was re-assessed. Detected concentrations of volatile organic compounds in soil vapor indicated that remedial actions were warranted for the site. Interim measures, including implementation of a soil vapor extraction system, were proposed to address the residual VOCs present at the site.

Site Remediation Strategy Development, *Los Angeles, California*. A site investigation and remediation strategy was developed to address contamination due to a former vapor degreaser at the site. As a result of a potential property transaction, historical contamination from a former vapor degreaser pit was identified. Detected concentrations of volatile organic compounds in soil vapor and groundwater indicated that remedial actions were warranted for the site. A focused soil vapor extraction and in-situ chemical oxidation strategy was proposed to address the residual VOCs present at the site.

Soil Remediation Completeness Evaluation, *Carson, California*. A regulatory determination of no further action for soil was needed to obtain a certificate of occupancy for the affordable senior housing redevelopment project constructed at this site. A team comprised of Geosyntec, the developer, and the existing consultant worked to upgrade the mitigation system operations and formalize the system operations and maintenance plan. This effort convinced the Regional Water Quality Control Board that the corrective actions for soils were sufficient to prevent unacceptable exposures to building occupants due to the vapor intrusion pathway and allowed the client to receive a certificate of occupancy for the development.

Groundwater Monitoring and Corrective Measures Study Evaluation, *San Diego, California*. Managed a groundwater monitoring program and corrective measures study evaluation for a chlorinated solvent release site at a commercial research and development facility. Groundwater monitoring was performed to assess the fate and transport of chlorinated solvents and 1,4-dioxane migrating in groundwater. The corrective measures study included an evaluation of source removal using soil vapor/dual-phase extraction, boundary control using phytoremediation, and monitored natural attenuation. Subsequent

NAPL Recoverability Evaluation, *Carson, California*. Conducted an evaluation of the recoverability of non-aqueous phase liquids (NAPL) at a former refinery. Site investigation activities included the use of laser induced fluorescence probes along with detailed soil and NAPL characterization. The data were interpreted using the API spreadsheet tools to estimate the recoverable NAPL at the facility and assess the potential risk reduction resulting from traditional NAPL recovery methods.

Geosyntec consultants

Litigation Support, *Ontario, California*. Provided expert support for a litigation case in southern California. A forensic assessment, including a review of available site investigation data along with facility operations information, was conducted to identify potential sources to PCB and chlorinated solvent impacts detected in soils at a light industrial facility. Additionally, an assessment of corrective action requirements for the site was conducted.

RCRA CMS Work Plan, *Norco, Louisiana*. Completed RCRA CMS work plan for a chemical plant in southern Louisiana. Louisiana Department of Environmental Quality risk-based rules were used in the CMS work plan preparation to develop a corrective action strategy for the site. The use of engineering controls and monitored natural attenuation were included in the CMS work plan.

Site Remediation, *Taft, Louisiana*. A risk-based assessment for a former chemical manufacturing site was conducted following the Louisiana risk-based corrective action program (RECAP). A corrective action strategy was developed and implemented. Upon completion of the remediation, a Ready for Reuse determination was received from LDEQ and USEPA.

Human Health Risk Assessments

Mr. Ettinger has conducted risk assessments for a wide range of sites ranging from underground storage tank release sites and agricultural chemical sites to refineries and chemical plants. He has conducted risk assessments as part of site corrective action to assist in remedial strategy development and identify areas requiring remediation, engineering and/or institutional controls. Mr. Ettinger has also conducted risk assessments to aid in site redevelopment planning.

Relevant human health risk assessment experience for Mr. Ettinger includes:

Human Health Risk Assessment, *Carson, California*. Developed a strategy and database tools to conduct a human health risk screening evaluation for a residential development constructed at a historical crude oil storage facility. Risk screening evaluations are prepared on a property-by-property basis and updated as new data are collected. The methods developed for this project provide a cost-effective approach to perform over 250 risk screening evaluations and can be combined with geographic information system (GIS) software to provide an assessment of the screening risk results across the entire site.

CMS Risk Assessment, *Torrance, California.* Conducted a vapor intrusion and human health risk assessment for a chlorinated solvent release site at a commercial building complex as part of the RCRA Corrective Action program for the site. The vapor intrusion assessment included the collection of sub-slab soil vapor data, indoor air data, and vapor intrusion modeling to assess the vapor intrusion pathway for this site. CalEPA/DTSC vapor intrusion guidance was followed in the collection and interpretation of these data. Following the data analysis, we worked with client and regulatory agency to communicate findings to building occupants. The human health risk assessment was conducted to identify remedial goals and focus proposed remedial actions.

Recently, a post-remedial action vapor intrusion risk characterization was completed as part of the regulatory site closure request.

Redevelopment Risk Assessment, *Long Beach, California*. Conducted human health risk assessment for the redevelopment of a former manufacturing location with chlorinated solvent impacted soil and groundwater. The risk assessment considered potential exposures during the redevelopment as well as future uses. Evaluation of risk reduction due to engineering controls was also included.

Radiological Performance Assessment, *Malaysia*. Conducted a radiological performance assessment to evaluate potential long-term doses for a low- and mid-level radioactive waste disposal facility in Malaysia. The performance assessment included a sensitivity analysis to understand critical parameters that would affect the calculated dose estimates and an uncertainty analysis to provide a range of estimated doses for the disposal facility to assist in project planning.

Soil Emissions Estimation and Design of Soil Vapor Remediation Systems

Mr. Ettinger has evaluated vadose zone fate and transport processes including soil emissions estimation and soil vapor extraction remediation systems. He has developed models for improved soil vapor extraction (SVE) system design. The models define the zone of remediation for SVE systems and incorporate the use of 2-dimensional analytical models for SVE design. Mr. Ettinger has also been an invited lecturer on theory, design, and implementation of SVE and air sparge systems for soil and groundwater remediation graduate course at a Rice University.

Relevant remediation experience for Mr. Ettinger includes:

Bioventing Pilot Test, *Carson, California*. Conducted a series of bioventing pilot test to evaluate the feasibility of this technology to remediate soils in a residential neighborhood impacted by crude oil. The pilot test evaluated the effectiveness of bioventing system with traditional vertical extraction well and horizontal trench designs. Data collected during the pilot test were used to calculate biodegradation rate constants and develop a strategy to implement this technology in the remedial action plan prepared for the site.

Bioventing System Design, ***Del Amo Superfund Site,*** *Los Angeles, California*. Designed SVE system for unsaturated soils beneath waste pits to limit contaminant migration from the source area to groundwater at the Del Amo Superfund Site. The SVE system design, a novel bioventing design was evaluated to limit off-gas treatment requirements.

Vapor Migration Modeling Validation Study, *Sacramento, California*. Conducted a vapor migration model validation study for a chlorinated solvent plume at a Superfund site. A field investigation program was implemented to collect site-specific soil physical property and soil vapor concentration profile data. These results were used to validate the vadose zone modeling to be used in the vapor intrusion assessment for the RI/FS. A probabilistic confidence analysis was included as in this study to support the modeling results.

Soil Vapor Extraction System Design, *Carson, California*. A flow-based model was used to evaluate SVE pilot tests results and develop a conceptual design for a full scale system. Systems are planned for a 2-acre chemical release area and 50 – 100 acre former refinery process area.

Vapor Migration Modeling Validation Study, *Ventura County, California*. Developed model to evaluate potential chlorinated solvent emissions from contaminated soil and groundwater at a fractured bedrock site. A field investigation program has been prepared to demonstrate the validity and calibration of the proposed model. The field investigation includes the collection of soil gas, surface flux, and ambient air data to collect data to test the vapor flux and dispersion model.

PROFESSIONAL EXPERIENCE

Geosyntec Consultants, Santa Barbara, CA, 2003-present
Shell Global Solutions (US) Inc., Houston, TX, 2002-2003
Equilon Enterprises LLC, Houston, TX, 1997-2002
Shell Oil Products Company, Houston, TX, 1995-1997
Shell Development Company, Houston, TX, 1989-1995

REPRESENTATIVE PUBLICATIONS

10-01 Majcher, E., Himmelheber, D. Krasnopoler, A., Nicholson, P., McAlary, T., Ettinger, R., Harris, J., Wrobel, J., “Implementation of a Strategic Approach for Complex VI Assessment at a Large Military Facility.” Air and Waste Management Association’s Vapor Intrusion 2010. Chicago, IL, September 29-30.

09-01 McAlary, T. R. Ettinger, P. Johnson, B. Eklund, H.Hayes, D.B. Chadwick, and I. Rivera-Duarte, 2009. “Review of Best Practices, Knowledge and Data Gaps, and Research Opportunities for the U.S. Department of Navy Vapor Intrusion Focus Areas.” US Navy Space and Naval Warfare Systems Center Pacific (SSC Pacific), Technical Report 1982, May.

09-02 Abreu, L.D.V, R.A. Ettinger, and T. McAlary. 2009. “Simulated Soil Vapor Intrusion Attenuation Factors Including Biodegradation for Petroleum Hydrocarbons.” *Groundwater Monitoring and Remediation*, vol. 29, no. 1: 105-117.

09-03 Johnson, P.C., R.A. Ettinger, J. Kurtz, R. Bryan, and J.E. Kester. 2009. “Empirical Assessment of Ground Water-to-Indoor-Air Attenuation Factors for the CDOT-MTL Denver Site.” *Groundwater Monitoring and Remediation*, vol. 29, no. 1: 153-159.

Geosyntec consultants

07-01 Abreu, L.D.V, R.A. Ettinger, and T. McAlary. 2007. "Application of 3D Numerical Modeling to Assess Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Sites." Proceedings of the Air and Waste Management Association's Vapor Intrusion: Learning from the Challenges Symposium. Providence, RI, September 26 – 28.

05-01 McAlary, T.A., R.A. Ettinger and P.C. Johnson, 2005. "Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air." EPRI, Palo Alto, CA, 2005, EPRI Document #1008492.

02-01 DeVaull, G.E., R.A. Ettinger, and J.B. Gustafson. 2002. "Chemical Vapor Intrusion from Soil or Groundwater to Indoor Air: Significance of Unsaturated Zone Biodegradation of Aromatic Hydrocarbons." *Soil and Sediment Contamination*, vol. 11, no. 3: 625-641.

97-01 DeVaull, G.E., R.A. Ettinger, J.P. Salanitro, and J.B. Gustafson. 1997. "Benzene, Toluene, Ethylbenzene, and Xylenes [BTEX] Degradation in Vadose Zone Soils During Vapor Transport: First-Order Rate Constants." Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water – Prevention, Detection, and Remediation Conference, November 12-14, Houston, Texas.

94-01 Gustafson, J.B., P.C. Johnson and R.A. Ettinger. 1994. "Screening Level Model for Soil Vapor Extraction Applications: The Effective Radius of Remediation." In Proceedings of the Twenty-Sixth Mid-Atlantic Industrial Waste Conference, August 7-10, Newark, DE.

94-02 Johnson, P.C. and R.A. Ettinger. 1994. "Considerations for the Design of In-Situ Vapor Extraction Systems: Radius of Influence vs. Zone of Remediation." *Ground Water Monitoring and Remediation*, vol. 13, no. 3: 123-128.

92-01 Savant-Malhiet, S.A., R.A. Ettinger, E.J. Stones and I.J. Dortch. 1992. "Prediction of the Simultaneous Evaporation and Infiltration of Ponded Hydrocarbon Mixtures." *Hydrocarbon Contaminated Soils and Groundwater*, vol. 5. E.J. Calabrese and P.T. Kostecki, eds., Lewis Publishers, Boca Raton, FL.

92-02 Chiang, C.Y., P.D. Petkovsky, R.A. Ettinger, I.J. Dortch, C.C. Stanley, R.W. Hastings and M.W. Kemblowski, 1992. "Passive Recovery Trench Design under the Influence of Tidal Fluctuations." *Hydrocarbon Contaminated Soils and Groundwater*, vol. 2, E.J. Calabrese and P.T. Kostecki, eds., Lewis Publishers, Boca Raton, FL.

91-01 Johnson, P.C. and R.A. Ettinger. 1991. "Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings." *Environmental Science & Technology*, vol. 25, no. 8:1445-1452.

INVITED PRESENTATIONS

Ettinger, R.A., 2017. Vapor Intrusion Pathway Investigations and Risk-Based Decision Making – Looking Beyond Generic Screening Levels. Groundwater Resources Association of

California Assessment and Remediation of Dry Cleaner Sites Symposium, Concord, CA, 2 November 2017.

Ettinger, R.A., 2016. TCE Short-Term Action – Dealing with Uncertainties for Vapor Intrusion Assessments. Northwest Remediation Conference, Cleaning Up & Re-Using Contaminated Properties, Seattle, WA, 4 October 2016.

Ettinger, R.A., 2016. Risk Management Strategies to Address Vapor Intrusion Assessment and Mitigation Uncertainties. 25th Groundwater Resources Association Annual Meeting, Groundwater Supply, Quality and Sustainability, The Challenges Ahead, Concord, CA. 29 September 2016.

Ettinger, R.A., 2016. Indoor Air Background Concentration Trends. AEHS 26th Annual International Conference on Soil, Water, Energy, and Air, San Diego, CA, 23 March 2016.

Ettinger, R.A. and Williams. S., 2015. Management Strategies to Address TCE Short-Term Action Levels at Potential Vapor Intrusion Sites. Industrial Environmental Association 31st Annual Statewide Environmental Training Symposium and Conference, San Diego, CA. 29-30 October, 2015.

Ettinger, R.A., 2014. Overcoming Challenges to Vapour Intrusion Assessments. Australian Land & Groundwater Association Ecoforum Conference and Exhibition, Gold Coast, QLD, Australia. 29-13 October 2014.

Ettinger, R.A., 2014. Novel Approaches for Evaluating the Vapor Intrusion Pathway. Groundwater Resource Association of California GRACast Web Seminar Series on Vapor Intrusion – Vapor Intrusion Investigation and Regulation. 17 September 2014.

Ettinger, R.A. and Zhou, D., 2014. Vapor Intrusion Modeling for Multi-Family Residential Units Above a Parking Garage. Air & Waste Management Association Vapor Intrusion, Remediation, and Site Closure Specialty Conference, Cherry Hill, NJ, 10-11 September 2014.

Ettinger, R.A., 2012. The Vapor Intrusion Pathway – Twenty Years After the J&E Model. Keynote Presentation at the AWMA Vapor Intrusion Specialty Conference, Denver, CO, 3 October 2012.

Ettinger, R.A., 2012. Recent Developments to Improve the Evaluation of Vapour Intrusion of Petroleum Hydrocarbons from Groundwater. Society of Brownfields Risk Assessment 2012 Summer Workshop, Bristol, England, 28 June 2012.

Ettinger, R.A. and Kerfoot, H., 2012. Evaluating the Vapor Intrusion Pathway for Methane. AEHS 22nd Annual International Conference on Soil, Water, Energy, and Air, San Diego, CA, 21 March 2012.

Ettinger, R.A., 2011. Vapor Intrusion Modeling and Risk Management, San Diego County 2011 Site Assessment and Mitigation Fall Forum, San Diego, CA, 22 September 2011.

Geosyntec consultants

Ettinger, R.A., 2011. Challenges to Multiple Lines of Evidence Vapor Intrusion Pathway Evaluations for Petroleum Release Sites, AEHS 21st Annual International Conference on Soil, Water, Energy, and Air, San Diego, CA, 14-17 March 2011.

Ettinger, R.A., Challenges to Evaluating the Vapor Intrusion Pathway for Occupational Environments, American Industrial Hygiene Association, Yuma Pacific-Southwest Section, 36th Annual Meeting, San Diego, CA, 19-21 January 2011.

Ettinger, R.A., Bishop, C., Faulk, R., ASTM Standard on Vapor Intrusion, Webinar hosted by Lorman Education Services, August 24, 2010.

Ettinger, R.A., Managing Uncertainties for Risk-Based Decision Making at Vapor Intrusion Sites, *Midwestern States Risk Assessment Symposium*, Indianapolis, IN, November 3-4, 2009.

Tesfamichael, A., Creamer, T.N., Ettinger, R.A., Garg, S., and Patterson, R.H., An Innovative Approach to LNAPL Distribution and Recoverability Assessment for a Large Industrial Site, *19th Annual AEHS Meeting and West Coast Conference*, San Diego, CA, March 9 – 12, 2009.

Abreu, L. and Ettinger, R.A, Understanding the Conceptual Site Model for Vapor Intrusion Into Buildings, *USEPA National Forum on Vapor Intrusion*, Philadelphia, PA, January 12 - 13, 2009.

Creamer, T., Tesfamichael, A., Ettinger, R., and Garg, S., Innovative Methodology for Assessing the Feasibility of LNAPL Hydraulic Recovery, *15th Annual International Petroleum & Biofuels Environmental Conference*, Albuquerque, NM, November 11-13, 2008.

Ettinger, R.A., ASTM's New Standard for Vapor Intrusion: the Good, the Bad and the Ugly, *Los Angeles County Bar Association Seminar*, October 23, 2008.

Ettinger, R.A., Recent Developments in Vapor Intrusion Investigations and Regulations, *Tri-Service Environmental Risk Assessment Work Group Meeting*, Port Hueneme, CA, September 10, 2008.

Ettinger, R.A., Evaluation of the Effect of Vadose Zone Biodegradation on Vapor Intrusion at Petroleum Hydrocarbon Sites. *Assessment and Remediation of Oxygenates and Other Fuel Components*. Sponsored by NEIWPCC, API, and ASTSWMO. October 22 - 23, 2007.

Ettinger, R.A., L. Abreu, T. McAlary. Evaluation of the Effect of Vadose Zone Biodegradation on Vapor Intrusion at Petroleum Hydrocarbon Sites. *Vapor Intrusion Mitigation Workshop*. Sponsored by NEWMOA and Brown University. June 11 - 12, 2007.

Ettinger, R.A., S. Costello, K. Tolson, and C. Caulk. Quantitative Evaluation of Soil Gas Profile Data for the Assessment of the Vapor Intrusion Pathway. *The Seventeenth Annual AEHS Meeting and West Coast Conference on Soils, Sediments, and Water,* San Diego, CA. March 19-22, 2007.

Ettinger, R.A. Vapor intrusion evaluation strategy and modeling developments. *California Industrial Hygiene Council's 16th Annual Conference*, San Diego, CA. December 4-6, 2006.

McAlary, T.A., R.A. Ettinger, and K. Berry-Spark, 2006. "Practical Considerations for Vapor Intrusion Investigations," an Invited Platform Presentation and Extended Abstract in: *Proceedings of the Air and Waste Management Association Specialty Conference on Vapor Intrusion*, Philadelphia, January 2006.

Ettinger, R.A. Vapor intrusion modeling for contaminated properties. *RTM Contaminated Property Transaction Symposium*, Cambridge, MA. October 19, 2005

McAlary, T.A., and R.A. Ettinger, 2005. Key Considerations for Vapor Intrusion Evaluations, *American Bar Association Joint Fall CL Meeting*, San Francisco, CA, September 17, 2005.

Ettinger, R.A. and T. McAlary. Site-specific vapor intrusion evaluation including biodegradation. *Battelle In-Situ and On-Site Bioremediation Symposium*, Baltimore, Maryland. June 6 – 9, 2005.

Ettinger, R.A. Identifying key factors and preferred lines of evidence. *EPRI MGP Site Management Program Subsurface Vapor Intrusion (SVI) to Indoor Air Workshop*, Jupiter, FL, December 11-12, 2003.

Ettinger, R.A. The impact of background concentration on vapor intrusion assessment. *Groundwater Resources Association Symposia, Subsurface Vapor Intrusion to Indoor Air: When is Soil and Groundwater Contamination an Indoor Air Issue?* San Jose, CA September 30 and Long Beach, CA October 1, 2003.

Ettinger, R.A. and L. Hay Wilson. Practical considerations for the assessment of the vapor migration to indoor air pathway. *2001 Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation*. Conference and Exposition, Houston, TX, November 13, 2001.

Ettinger, R.A. Conceptual model for migration of volatile contaminant vapors into buildings. *USEPA RCRA Environmental Indicators Forum*, Washington, D.C., August 2000.

WORKSHOPS

Data Evaluation for Vapor Intrusion Studies. Air and Waste Management Association Vapor Intrusion, Remediation, and Site Closure Specialty Conference. Cherry Hill, NJ, 9 September, 2014.

Trends and Developments in Cleanup Levels for Petroleum Hydrocarbons and PAHs in Soil. The 24th Annual West Coast Conference on Soils, Water, Energy, and Air, San Diego, CA. March 18, 2014.

Vapor Intrusion Pathway: A Practical Guideline. Sponsored by ITRC. Denver, CO, October 3-4, 2011; Cambridge, Massachusetts, July 12-13, 2010; Sacramento, CA, June 22-23, 2009; Long Beach, CA, June 25-26, 2009.

Vapor Intrusion Pathway Modeling: Development and Application. Air and Waste Management Association's Vapor Intrusion 2010. Chicago, IL, September 28, 2010.

Application of Risk Assessment for Environmental Decision Making at Petroleum UST Sites. Co-sponsored and supported by the California State Water Resources Control Board and the USEPA, Orange, CA, June 23-24, 2010; Sacramento, CA, March 17-18, 2010; Palm Desert, CA, March 26-27, 2008; Orange, CA, February 27 - 28, 2008; Sacramento, CA, October 30 -31, 2007; San Diego, CA, November 8-9, 2006; Sacramento, CA, September 7-8, 2006; Los Angeles, CA, June 7-8, 2006; Los Angeles, CA, June 1-2, 2005; Sacramento, CA, April 4-5, 2005; San Diego, CA, January 19-20, 2005; San Diego, CA, April 6-7, 2004.

Soil Gas Sampling Field Demonstration and Lecture. Presented to California Environmental Protection Agency Department of Toxic Substances Control, and State Water Resources Control Board Staff and Regional Water Quality Control Board Staff. Sacramento, CA, May 27, 2009.

Vapor Intrusion Evaluation Strategy and Modeling Developments. California State Water Resources Control Board Technology Forum, Los Angeles, CA, October 22, 2008.

Characterization and Evaluation of Vapor Intrusion (VI). Air and Waste Management Association Vapor Intrusion: The Next Great Environmental Challenge – An Update, Los Angeles, CA. September 13-15, 2006.

Managing Vapor Intrusion Sites. Battelle Remediation of Chlorinated and Recalcitrant Compounds: The Fifth International Conference, Monterey, CA. May 22-25, 2006.

Technical Guidance for Indoor Air Vapor Intrusion. Sponsored by Severn Trent Laboratories. San Pedro, CA, February 22, 2005 and Alamo, CA, February 24, 2005.

Evaluating the Vapor Pathway: Soil Gas Sampling Procedures. 2004 Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation, Conference and Exposition, Baltimore, MD, August 16, 2004.

Evaluating the Vapor Intrusion to Indoor Air Pathway Workshop. 2001 Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation, Conference and Exposition, Houston, TX, November 13, 2001.

Indoor Air Pathway and Risk Based Decision-Making Workshop. Presented to state regulators in Region 10 and Region 5. February 28 – March 1, 2001 and June 27-28, 2001.

Risk Assessment Demonstration Project Workshops. Sponsored by USEPA/AIHC, April 23-24, 1997 and June 11-12, 1997.

D. Nadine Weinberg

Nadine Weinberg

Ms. Weinberg is a Partner in the Boston MA office with more than 20 years of experience working on projects involving the evaluation of human health risks, chemical exposures, and regulatory advocacy, including over fifteen years focused on the vapor intrusion pathway.

On behalf of industrial and chemical manufacturing clients, Ms. Weinberg has completed multiple vapor intrusion evaluations in accordance with USEPA and state guidelines. These evaluations have included identification of strategic approaches to address vapor intrusion, modeling of the vapor intrusion pathway, development of sampling work plans, assessment of soil gas and indoor air data including the determination of potential human health risks, and negotiations with regulatory agencies.

Ms. Weinberg has represented clients on several litigation cases and has experience writing expert reports, conducting depositions, and participating in trials.

Ms. Weinberg is also focused on supporting clients on emerging chemical issues and regulatory risk issues. Ms. Weinberg has worked closely with clients and trade associations to understand and evaluate the most current regulations and guidance. This includes vapor intrusion issues as well as issues related to chlorinated solvents, and other high profile chemicals in the environment.

Professional Affiliations & Registrations

- Member, Air and Waste Management Association

Fields of Competence

- Vapor Intrusion
- Human Health Risk Assessment
- Litigation Support
- Expert Witness
- Regulatory Agency Negotiation
- Emerging Chemical Issues
- Vapor Intrusion Modeling
- Soil Gas and Indoor Air Sampling Work Plans
- Data Evaluation and Exposure Assessment

Key Industry Sectors

- Chemical
- Manufacturing
- Aerospace
- Technology, Media, and Telecom

Education

- M.E.M., Resource Ecology, Duke University, Nicholas School of the Environment, 1993
- B.S., Natural Resources, Cornell University, College of Agriculture and Life Sciences, 1989

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Presentations and Publications

Nelson, D., K. Sellers, N. Weinberg. 2017. Contaminants Emerging from a New Look at Old Chemicals of TSCA Reform. Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies. May.

Lutes, C., N. Weinberg, R. Truesdale, B. Schumacher, R. Norberg. 2017. Evaluation of Indoor Air Concentrations and Exposures and Implications for Indoor Air Sampling Approaches. Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies. May.

Weinberg, N., E. LeBlanc. 2016. Evaluation of USEPA's New Policy for TCE Vapor Intrusion. Proceedings of the Air and Waste Association Conference. Vapor Intrusion, Remediation, and Site Closure. San Diego CA. Dec 7.

Weinberg, N., K. Eyre, D. Scillieri. 2015. Building a Vapor Intrusion Case: Use of Multiple Lines of Evidence to Support a Site Conceptual Model for TCE Migration Under a Residential Neighborhood. 25th Annual International Conference on Soil, Water, Energy, and Air. San Diego CA. March 25.

Weinberg, N., C Lutes, R Norbert, R Truesdale, B Schumacher. 2014. A Risk Assessment Comparison: Evaluation of Relevant Indoor Air Exposure Concentrations and Periods and Implications for Developing Indoor Air Sampling Plans. Proceedings of the Air and Waste Management Association Conference. Cherry Hill, NJ. September

Weinberg, N. C Lutes, R Norbert, R Truesdale, B Schumacher. 2014. A Risk Assessment Comparison: Evaluation of Relevant Indoor Air Exposure Concentrations and Periods and Implications for Developing Indoor Air Sampling Plans. Air and Waste Management Association Conference. Cherry Hill, NJ. September 10.

Weinberg, N. 2014. Recent Regulatory Developments & Technical Strategies for Managing Risks and Achieving Permanent Closure at Sites. Presented to American Bar Association 23rd Annual Spring CLE Meeting April 4.

Engler, C., R. Saari, N. Weinberg, C. Lutes. 2014. Design and Operations of Sub-slab Depressurization Systems in a One Million Square Foot Commercial Multi-tenant Building. 24th Annual International Conference on Soil, Water, Energy, and Air. March 17-20.

Weinberg, N., C. Grogan, J. Manzo, P. Barnett. 2014. Evaluation of Attenuation Factors and Building Construction in Predicting Vapor Intrusion. 24th Annual International Conference on Soil, Water, Energy, and Air. March 17-20.

Weinberg, N., A. Wolford, A. Korik, A. Fortune, S. Sommers. 2012. Evaluation of the Potential Influences of Modeling Clay on Sub-slab Sampling Results. Proceedings of the Air and Waste Management Association. VI Specialty Conference. Denver CO. October 3-4.

Weinberg, N., E. Christy, M. Wacksman, and R. Chatrathi. 2012 Vapor Intrusion at Railroad Properties: Investigation, Evaluation, and Recent Regulatory Developments. Railroad Environmental Conference. October 17.

Lutes, C., R., Studebaker, R. Uppencamp, L. Abreu and N. Weinberg. 2011. Efficient Assessment and Mitigation of Vapor Intrusion: Optimal Sub-slab Depressurization Design Strategies and Handling the Problems of Variability with Long-term Integrated Samplers. Oral Presentation at USEPA Workshop: Addressing Regulatory Challenges in Vapor Intrusion, AEHS Conferences San Diego CA, Mar 15, 2011.

Weinberg, N. 2010. Weight of Evidence Evaluations: A Comparative Analysis of Human and Ecological Approaches. SRA 29th Annual Meeting. Portland OR. December 8.

Weinberg, N. 2009. Evaluation of Site-Specific Data for Developing Conceptual Site Models. Air and Waste Management Association. Detroit MI. June 17.

Key Projects

TCE and Vapor Intrusion Advocacy
Washington DC
Working with the trade association and member aerospace companies, prepared talking points and power point slides to present to the Office of Management and Budgeton the USEPA current Vapor Intrusion Guidance as well as short term TCE screening levels.

On-going work with the trade association and aerospace members includes detailed research on TCE vapor intrusion sites to identify similarities and differences in approaches including regulatory triggers; regulatory support and prepartion of comments on recent state and USEPA guidance; and review of proposed toxicity studies.

1,4-Dioxane and Vapor Intrusion Advocacy
Washington DC
Working with the trade association and member aerospace companies, supported organization of a 1,4-dioxane panel. The panel was developed to advocate for the best available science under the new Lautenberg Chemical Safety Act. On-going work includes supporting comment preparation and reviewing proposed toxicity studies.

Emerging Chemical Support
Bethesda MD
Manager responsible for supporting an aerospace company on emerging chemical issues. Worked closely with remediation team and legal counsel to develop an overall strategy including ranking system to identify emerging chemicals. Prepared spreadsheets with rankings and summary information to focus program objectives. Support development of a interview form for use at individual sites to identify potential uses of emerging chemicals. Prepare white papers on individual emerging chemicals that cover toxicity and regulatory information.

Vapor Intrusion Evaluation and Litigation Support
Tallevast, FL
Lead investigator evaluating on-site and off-site vapor intrusion data for an aerospace company. For on-site buildings, directed sampling program and data evaluation. For on and off-site buildings, developed a weight of evidence evaluation that considered (1) the site constituents of concern, (2) the relationship between indoor air and soil gas results, (3) background concentrations; and (4) the location of soil gas results in relation to the defined groundwater plume. The vapor intrusion evaluations were accepted by FDEP and no further investigation was required.

Provided expert testimony for client regarding the vapor intrusion pathway during administrative hearings and court case. Prepared exhibits describing the data collected and demonstrating the lack of a complete vapor intrusion pathway. Case was decided in Lockheed Martin's favor and vapor intrusion was not identified as a pathway of concern.

Risk Assessment Expert Review and Litigation Support Laredo TX
Expert hired to evaluate potential for indoor air risks at an occupied commercial building. Calculated indoor air risks from site-specific data, including both indoor and ambient air. Compared estimated indoor air risks to background risks. Prepared expert report that was submitted on behalf of client involved in case.

Vapor Intrusion Expert Review and Litigation Support Madison WI
Lead technical manager for vapor intrusion evaluation at active industrial facility surrounded by residential homes. Reviewed exterior soil gas and residential sub-slab and indoor air data. On behalf of counsel, hired as Expert to provide opinion on vapor intrusion pathway. Prepared Expert Report regarding potential for vapor intrusion at residential homes. Completed deposition on behalf of client. Case was settled prior to trial.

Vapor Intrusion Study
Great Neck, NY
Executed vapor intrusion study at a one million square foot building formerly owned and operated by an aerospace company. Supervised multiple field sampling events that involved the collection of sub-slab soil gas and indoor air samples from over 85 locations. Prepared vapor intrusion work plans and reports that presented all data results and made recommendations for future samples. Worked with team to develop understanding of vapor intrusion conditions including TCE and PCE soil

gas plumes under building and identify strategy for addressing overall vapor intrusion issues.

Vapor Intrusion Evaluation, Support, and Expert Services
Morrison, IL
Working with a manufacturing client, developed strategy to evaluate the vapor intrusion pathway downgradient of the site. Prepared off-site vapor intrusion sampling work plan and oversaw the collection of sub-slab soil gas, indoor air, and ambient air data. Prepared letters to residents describing results. Negotiated acceptable risk-based screening levels. Prepared vapor intrusion reports for USEPA and Illinois EPA including a Tier 3 Vapor Intrusion Assessment under the TACO program.

Hired by client to also support litigation on site. Prepared expert report to counter claims that vapor intrusion was occurring at nearby residential homes and that the pathway had been fully evaluated.

Vapor Intrusion Due Diligence Support
United States
Reviewed and evaluate Phase I Environmental Site Assessments for potential vapor intrusion issues at sites across the country. Identify sites where follow up assessments are needed including modeling and/or on-site sampling. Design and oversee sampling and prepare summary reports describing data results. To date, approximately 50 sites have been reviewed, with over 10 sites needing follow up sampling.

Multiple Lines of Evidence Analysis
Muncie IN
Reviewed site conceptual model and recent and historical soil gas data from site to support development of a multiple lines of evidence analysis for vapor intrusion. Prepared report that demonstrated that client was not responsible for elevated levels of constituents in soil gas at property boundary. Report submitted to state agency is waiting review.

Corporate Vapor Intrusion Guidance
Bethesda MD
Working with legal counsel and environmental project managers, developed Corporate vapor intrusion guidance. Guidance provides detailed information for conducting a vapor intrusion investigation including sampling, analysis and mitigation options. Developed one-page summary and powerpoint for use in Corporate meetings.

Vapor Intrusion Evaluation and Strategy Development Millsboro, DE
Worked with client group and USEPA to develop vapor intrusion plan to evaluate TCE in groundwater. Developed public communication materials. Based on initial results, prepared weight of evidence evaluation for TCE vapor intrusion. Successfully completed indoor and sub-slab sampling in one commercial facility and 16 apartments within 2 large apartment complexes, and 3 residential homes. Report that showed that vapor intrusion was not occurring was accepted by USEPA and no further action was required.

Vapor Intrusion Evaluation and Strategy Development Puerto Rico
Lead technical manager and task manager for developing strategy and approach for evaluating vapor intrusion from separate phase hydrocarbon (SPH) located underneath a large airport. Interpreted initial data results and prepared overall approach for addressing findings.

Vapor Intrusion Strategy and Evaluation
Baltimore MD
Developed vapor intrusion strategy at site re-opened as part of a Superfund 5-year review. Five off-site commercial buildings were identified for further evaluation. Prepared necessary work plans and obtained approval USEPA. Worked with team to obtain access and collect necessary data. TCE and PCE were identified in sub-slab soil gas in some buildings. Completed data evaluation that indicated that mitigation was only needed in one building. Monitoring is being proposed for other off-site buildings.

Vapor Intrusion Assessment
Woburn, MA
Lead technical manager for vapor intrusion study at on-site building and residential neighborhood. Prepared work plan for sampling and worked with USEPA to meet with nearby residents. Oversaw the collection of two rounds of sub-slab soil gas, indoor air, and ambient air sampling. Completed individual building reports that included both a weight of evidence approach as well as

site-specific risk calculations for a residential inhalation pathway. Results were accepted by USEPA and on-going monitoring continues at only one off-site commercial building.

Vapor Intrusion Support and Strategy
Hattiesburg MS
Technical vapor intrusion lead providing oversight and strategy regarding investigation of the vapor intrusion pathway. Considered both off-site residential homes and on-site facility buildings. Assisted in development of vapor intrusion CSM and identified additional site-specific chemicals to evaluate. Prepared responses to state and federal regulatory agencies regarding data needs and vapor intrusion evaluation. Assisted in development of site-specific sampling plan including sampling for non-traditional chemicals using sorbent tube methods.

Vapor Intrusion Work Plan and Sampling
Moraine, OH
Prepared vapor intrusion strategy including work plan for soil gas and residential sub-slab and indoor air sampling at 60 downgradient residential homes. Negotiated sampling approach with USEPA and OEPA. Participated in public meeting to describe sampling approach to residents. Worked with team to develop information for distribution to residents. Evaluated data from a nearby landfill to determine if materials disposed in the landfill were contributing to detections in soil gas in the neighborhood.

Vapor Intrusion Evaluation and Support
Collingsdale, PA
Worked with team to develop soil gas sampling approach to evaluate potential vapor intrusion from VOCs in groundwater. Based on soil gas results outside building, identified next steps including sub-slab soil gas sampling. Worked with team to develop factsheets and other communication pieces to describe on-going work and results to building owner and tenants. Identified follow-up sampling needs and evaluated effectiveness of soil gas mitigation.

Vapor Intrusion Due Diligence Review
Newport CA
Provide technical review of data collection and data analysis conducted by sellers consultant. Worked with buyer and legal team to review assessment and evaluate the potential for vapor intrusion to affect building occupancy in the future. Identified and resolved potential concerns with data collection and data modeling results. Based on analysis, the buyer was able to move forward with the purchase.

Vapor Intrusion Oversight Support
California
Reviewed data collected to evaluate vapor intrusion pathway at both on- and off-site locations that includes a school and a large mobile home park. Provided senior oversight of data collection strategies and analysis. Worked with team to identify next steps and process for investigation. Reviewed human health risk assessment data and report.

Critical Evaluation of NY and NJ Guidance
Task manager for critical evaluation of New York State and New Jersey vapor intrusion guidance documents. On behalf of client, prepared comments that identified the limitations of the guidances and made recommendations for improvements.

Vapor Intrusion Sampling
Picatinny, New Jersey
Vapor Intrusion expert responsible for working with on-site command and field team to develop strategy for on-site buildings. Developed sampling strategy and negotiated sampling work plans with USEPA and NJDEP. Provided oversight to conduct sampling including the preparation of factsheets for distribution to building occupants. Worked with project team to organize and evaluate results, including a weight of evidence. Prepared final report of results that was accepted by USEPA and NJDEP for closure.

Vapor Intrusion Evaluation and Support
Phoenix , Arizona
Senior technical support responsible for reviewing final work plans and data reports. Worked with team to provide overall vapor intrusion strategy and direction at multiple buildings on site. Worked with USEPA Region 9 to develop appropriate screening approaches. Based on initial soil gas and indoor air data results, worked with team to clarify that concentrations inside several buildings were associated with background

concentrations. Obtain USEPA Region 9 approval on the approach and subsequent data reports.

Corporate Vapor Intrusion Policy
California
Prepared corporate vapor intrusion policy. Worked with legal counsel and environmental project managers to develop a policy for addressing vapor intrusion at sites. Policy addressed when a vapor intrusion investigation would be necessary and what the appropriate steps would be for completing the process. Prepared presentation for Environmental managers meeting. Based on feedback from client, revised policy and submitted to client. Policy was incorporated by corporate managers and used to guide all future vapor intrusion investigations.

E. Jordan Wilson

JORDAN WILSON, PH.D., P.E.
jlwilson@usgs.gov

EDUCATION

Ph.D. in Civil Engineering, Missouri University of Science & Technology, Rolla, MO, August 2013-2017
Topic: Vapor Intrusion Risk Assessment by Trees, Advisor: Joel G. Burken

M.S. in Environmental Engineering, Missouri University of Science & Technology, Rolla, MO, May 2013:
Thesis: Distribution And Occurrence Of Escherichia Coli In Water And Sediments At Grand Glaize Beach In Lake Of The Ozarks State Park, Advisor: Joel G. Burken

B.S. in Environmental Engineering, Missouri University of Science & Technology, Rolla, MO, May 2011, Summa Cum Laude

AWARDS/SCHOLARLY ACTIVITIES

2016 Student Paper Competition Winner at Tenth International Conference on Remediation of Chlorinated and Recalcitrant Compounds
2011-2017 Missouri S&T Chancellor's Fellow
2012 Special Thanks for Achievement (STAR) Award from United States Geological Survey
2011 Opportunities in Undergraduate Research Program Recipient
2011 Undergraduate Research Ambassador to the Missouri State Capital

PROFESSIONAL SOCIETIES

International Phytotechnology Society – Member
American Chemical Society – Member
American Water Resources Association – Member
National Ground Water Association – Member

WORK EXPERIENCE

Hydrologist, United States Geological Survey, Rolla, MO (May 2013 – Present)
Student Hydrologist, United States Geological Survey, Rolla, MO (May 2011 – May 2013)
Graduate Research Assistant, Missouri S&T, Rolla, MO (September 2012 – May 2013)
Undergraduate Research Assistant, Missouri S&T, Rolla, MO (February 2010 – May 2010)

PROFESSIONAL LICENSES

Registered Professional Engineer (P.E.) in Missouri (Environmental Engineering/2016/# 2016001321)
40-hr HAZWOPER Certified

SOFTWARE EXPERIENCE

MATLAB	ArcGIS/QGIS	SAS/Systat/JMP	Swift/Java (iOS/Android)
Python	ANSYS	MODFLOW	WellCAD
R	RockWorks	PEST++	VisIt/ParaView

Updated: 8/19/15

PAPERS

1. Wilson, J.L., Samaranayake, V.A., Limmer, M., Schumacher, J.G., Burken, J.G., Phytoforensics: Trees as Bioindicators of Potential Indoor Exposure Via Vapor Intrusion. *Public Library of Science ONE*. **In Review, 2018.**
2. Wilson, J.L., Samaranayake, V.A., Limmer, M., Schumacher, J.G., Burken, J.G., Contaminant Gradients in Trees: Directional Tree Coring Reveals Boundaries of Soil and Soil-Gas Contamination with Potential Applications in Vapor Intrusion Assessment. *Environmental Science and Technology*. **2017**. 51 (24), 14055-14064. DOI: 10.1021/acs.est.7b03466.
3. Wilson, J.L., Limmer, M., Samaranayake, V.A., Schumacher, J.G., Burken, J.G., Tree Sampling as a Method to Assess Vapor Intrusion Potential at a Site Characterized by VOC-Contaminated Groundwater and Soil. *Environmental Science and Technology*. **2017**. 51 (18), 10369-10378. DOI: 10.1021/acs.est.7b02667.
4. Limmer, M.A., Wilson, J.L., Westenberg, D., Lee, A., Siegman, M., Burken, J.G., Estimation of Benzene, Toluene, and Chlorobenzene Removal Rates by a Phytoremediation System. *International Journal of Phytoremediation*. **Accepted, 2017.**
5. Wilson, J.L., Remedial Investigation of the Vienna Wells Site: Maries County, Missouri, 2011-2016: Volume I. U.S. Environmental Protection Agency Remedial Investigation Report. **2017**.101 p. Available at https://semspub.epa.gov/work/07/30307677.pdf.
6. Wilson, J.L., Remedial Investigation of the Vienna Wells Site: Maries County, Missouri, 2011-2016: Volume II. U.S. Environmental Protection Agency Remedial Investigation Report. **2017**.101 p. Available at https://semspub.epa.gov/work/07/30307678.pdf.
7. Wilson, J.L., Schumacher, J., Burken, J.G., Persistence and Microbial Source Tracking of *Escherichia coli* at a Freshwater Swimming Beach at Lake of the Ozarks State Park, Missouri. *Journal of American Water Resources Association*. **2016**. 52 (2), 508-522. DOI: 10.1111/1752-1688.12404.
8. Wilson, J.L., Schumacher, J., Burken, J.G., Occurrence and Origin of *Escherichia coli* in Water and Sediments at Two Public Swimming Beaches at Lake of the Ozarks State Park, Camden County, Missouri, 2011-13. *U. S. Geological Survey Scientific Investigation Report 2014-5055*. **2014**. 59 p. DOI: 10.3133/sir20145005.
9. Wilson, J.L., Bartz, R., Limmer, M.A., Burken, J.G., Plants as Bio-Indicators of Subsurface Conditions: Impact of Groundwater Level on BTEX Concentrations in Trees. *Int. J. Phytorem.*. **2013**. 15 (3), 257-267, DOI: 10.1080/15226514.2012.694499.

FACT SHEETS

1. Wilson, J.L., 2017, Phytoforensics—Using trees to find contamination: U.S. Geological Survey Fact Sheet 2017–3076, 2 p. DOI: 10.3133/fs20173076.

CONFERENCE PAPERS

Wilson, J.L., Schumacher, J., Limmer, M., Burken, J.G., Phytoforensics: High Density, Low Cost, Tenth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Palms Springs, CA. May 22-26, 2016.

Bartz, R., Wilson, J.L., Limmer, M. A., Burken, J. G., Effect of Groundwater Depth on Aerobic Biodegradation of BTEX Using in-planta Measurements, Proceedings of the Bioremediation

and Sustainable Environmental Technologies Conference, Reno, NV, 2011, Battelle: Reno, NV, 2011.

PRESENTATIONS

Wilson, J.L.*, Schumacher, J.G., Limmer, M.A., Burken, J.G., *Trees as Indicators of Vapor Intrusion*. U.S. Geological Survey Columbia Environmental Research Center Seminar Series. Columbia, MO. September 6, 2017.

Wilson, J.L., Schumacher, J.G., Limmer, M.A., Burken, J.G.*, *Trees as Indicators of Vapor Intrusion.* University of Guelph, Ontario, Canada. June 2017.

Wilson, J.L., Schumacher, J.G., Limmer, M., Samaranayake, V.A., Burken, J.G.* *Trees as Indicators of Vapor Intrusion Risk*. 253rd American Chemical Society National Meeting. San Francisco, California. April 2-6, 2017.

Wilson, J.L.*, Schumacher, J., Limmer, M.A., Burken, J.G. *Phytoscreening for Vapor Intrusion Potential: Comparing Effects of Tree Diameter*. 12th International Phytotechnologies Conference. Manhattan, KS. September 27-30, 2015.

Limmer, M.A.*, Wilson, J.L., Westenberg, D., Burken, J.G. *Estimation of Benzene, Toluene and Chlorobenzene Removal Ratesby a Phytoremediation Plot*. 12th International Phytotechnologies Conference. Manhattan, KS. September 27-30, 2015.

Burken, J.G.*, Limmer, M.A., West, D., Wilson, J.L. *Phytoforensic Detection of Subsurface Geochemistry Reactions: Field, Laboratory and Classroom Applications*. 12th International Phytotechnologies Conference. Manhattan, KS. September 27-30, 2-15.

Burken, J.G.*, Sukharia, R., West, D., Wilson, J.L., Goodwin, T., *Novel Plant Sensing of Landfill Flaws*. 12th International Phytotechnologies Conference. Manhattan, KS. September 27-30, 2015.

Wilson, J.L.*, Limmer, M.A., Burken, J.G. *Phytoforensics and Novel Passive Samplers to Assess Vapor Intrusion Risk*. 250th ACS Conference. Boston, MA. Aug. 16-20, 2015.

Limmer, M.A.*, Wilson, J.L., Burken, J.G. *Advances in Phytoremediation: Calculating the Rooting Volume of Trees*. The Association of Environmental Engineering and Science Professors 2015 Conference. New Haven, CT. June 13-16, 2015.

Wilson, J.L.* *An Approach to Understanding E. coli at a Public Swimming Beach in* Missouri. Missouri S&T Biological Sciences Seminar Series. Rolla, MO. February 24, 2014.

Wilson, J.L.*, Schumacher, J., Burken, J.G. *Tracking Sources and Fate of E. coli Contamination at a Lake of the Ozarks Park Public Beach*, 17th Annual Mid-American Association of Environmental Engineers Conference. October 20, 2012.

Schumacher, J.*, Wilson, J.L.* Soil and Groundwater Sampling: Without Soil or Groundwater ….”Phytoforensics”. Missouri Department of Natural Resources Seminar Series. Jefferson City, MO. July 1, 2013.

Wilson, J.L.* *Occurrence and Origin of E. coli at Grand Glaize Beach at Lake of the Ozarks*, Missouri S&T Chancellor’s Fellowship Award Banquet. Rolla, MO. April 2, 2013.

Wilson, J.L.* *USGS-Missouri S&T E. coli Investigations at Lake of the Ozarks State Park.* Guest Lecturer for Missouri S&T Environmental Systems Modeling Class. Rolla, MO. September 30, 2014.

Wilson, J.L., Bartz, R., Limmer, M.A.*, Burken, J.G. *Plant Measurements of Aerobic Biodegradation of BTEX: Effect of Groundwater Depth*. 8th International Phytotechnologies Conference, Portland, OR. September 13-16, 2011.

Bartz, R, Wilson, J.L., Limmer, M.A.*, Burken, J.G. *Effect of Groundwater Depth on Aerobic Biodegradation of BTEX Using In-planta Measurements,* Battelle International Symposium on Bioremediation and Sustainable Environmental Technologies, Reno NV. June 27 – 30, 2011.

POSTERS

Wilson, J.L.* *Phytoforensics: High Density, Low Cost*. Tenth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Palms Springs, CA. May 22-26, 2016.

Wilson, J.L.*, Schumacher, J., Burken, J.G. *Phytoscreening for Vapor Intrusion Potential: Comparing Effects of Tree Diameter and Type*. Association of Environmental Engineering and Science Professors 2015 Conference. New Haven, CT. June 13-16, 2015.

Wilson, J.L.*, Schumacher, J., Burken, J.G., Limmer, M.A. *Occurrence and Origin of E. coli at Grand Glaize Beach at Lake of the Ozarks*, Missouri S&T Chancellor's Fellowship Poster Exhibition, Rolla, MO. April, 2015.

Limmer, M.A.*, Wilson, J.L., Burken, J.G. *Phytoforensics: Analytical Techniques for Assessing Plant Contamination*. EmCon 2014. Iowa City, IA. August 19-22, 2014.

Wilson, J.L.*, Schumacher, J., Burken, J.G. *Occurrence and Origin of E. coli at Grand Glaize Beach at Lake of the Ozarks*. 18th Annual Mid-American Association of Environmental Engineers Conference. St. Louis, MO. September 21, 2013.

Wilson, J.L.*, Schumacher, J., Burken, J.G. *Occurrence and Origin of E. coli at Grand Glaize Beach at Lake of the Ozarks*. The 50th Annual Association of Environmental Engineering and Science Professors Conference. Golden, CO. July 14-16, 2013.

Wilson, J.L.*, Schumacher, J., Burken, J.G. *Occurrence and Origin of E. coli at Grand Glaize Beach at Lake of the Ozarks*, Missouri S&T Chancellor's Fellowship Poster Exhibition, Rolla, MO. April, 2013.[1]

Wilson, J.L.*, Bartz, R.*, Limmer, M.A., Burken, J.G. *Effect of Groundwater Depth on Aerobic Biodegradation of BTEX using In-planta Measurements*, Missouri S&T Undergraduate Research Forum, Rolla, MO. April 6, 2011.[2]

Wilson, J.L.*, Bartz, R.*, Limmer, M.A., Burken, J.G. *Effect of Groundwater Depth on Aerobic Biodegradation of BTEX using In-Planta Measurements*. Undergraduate Research Day at the Capitol, Jefferson City, MO. March 3, 2011.

[1] 2nd Place Poster

[2] 3rd Place Poster

F. Ian Hers

Resumé IAN HERS

Golder Associates Ltd. – Burnaby

Education

Ph.D., Civil Engineering (Geoenvironmental), University of British Columbia, Vancouver, BC, 2004

M.A.Sc., Civil Engineering (Geotechnical), University of British Columbia, Vancouver, BC, 1988

B.A.Sc., Civil Engineering, University of British Columbia , Vancouver, BC, 1986

Professional Affiliations

Registered Professional Engineer, Association of Professional Engineers and Geoscientists of British Columbia

Roster of Professional Experts, BC Ministry of Environment

Director of the Board, Science Advisory Board for Contaminated Sites in BC

Member, Association of Groundwater Scientists and Engineers

National Ground Water Association

Employment History

Golder Associates Ltd. – Burnaby, BC
Principal, Senior Environmental Engineer (1988 to Present)

World-wide practice Leader for Golder Associates' vapour intrusion services. Provides review, technical advice, and program development planning for industrial and regulatory clients across North America, Australia, and Europe. Has directed research programs, developed guidance, and consulted to numerous federal, provincial and state agencies. Responsible for project direction and technical oversight of multi-disciplinary projects primarily related to site assessment, human health risk assessment, remedial investigations, and remediation feasibility studies and design for a wide range of contaminated sites. Provides specialist technical advice on assessment and modelling of subsurface chemical fate for groundwater and soil vapour, natural attenuation studies, design of remediation systems for sites contaminated with organic chemicals including assessment of LNAPL assessment and recovery and natural source zone depletion, soil vapour extraction, air sparging, enhanced biodegradation technologies, and design and construction of soil gas extraction and control systems for contaminated sites and landfills. Assisted in development of guidance and training on LNAPL management and Petroleum Vapour Intrusion for Interstate Technology and Regulatory Council (ITRC).

British Columbia Institute of Technology – Burnaby, BC
Instructor (1994 to 2005)

Instructor and former member of advisory committee for Bachelor of Environmental Engineering Technology program. Taught "Principles of Environmental Assessments and Audits", "Field Investigation Methods", and "Remediation Technologies". Responsible for supervision of two student research term projects.

University of British Columbia – Vancouver, BC
Professional Short Courses, Instructor and Guest Lecturer (2002 to 2015)

Developed and taught several modules of professional development short courses at UBC between 2002 and 2006, including Contaminated Sites Investigation and Management; Impact of New Regulations in BC; and Review of the New Regulatory Regime in BC and the Use of Screening Level Risk Assessments. In 2002, 2003 and 2015, co-instructor for Civil 408 Geoenvironmental Engineering course. Guest lecturer for courses in civil engineering on risk assessment, fate and transport of chemical and remediation technologies (Civil 411, 567 and 572) from 2002 to 2014. Ph.D. research on soil vapour transport and intrusion of VOCs into buildings. Co-supervisor post-doc research student 2010-2011 (Dr. Parisa Jourabchi).

M.A.Sc. Program
(1986 to 1988)

Course work included geotechnics, contaminant and resource hydrogeology and environmental engineering.

PROJECT EXPERIENCE – GUIDANCE DEVELOPMENT, APPLIED RESEARCH AND TRAINING COURSES

Health Canada Vapour Intrusion Guidance	Project researcher for preparation of Frequently Asked Question (FAQs) document to support Health Canada vapour intrusion guidance that covered conceptual site model development, application and use of models, investigation and mitigation. Reviewer of Health Canada vapour intrusion spreadsheet model implementing their guidance (2017). Reference Ms. Odette Bose. odette.bose@canada.ca
U.S. EPA Vapour Intrusion Guidance	Expert work group member and invited speaker for annual U.S. EPA VI workshop on latest science; presented on long-term stewardship and emerging approaches for monitoring and mitigation of VI, contributed to the expert work group on statistical methods and use of indicator, tracer and surrogate (ITS) approach to improve indoor air monitoring programs (2014-2017). Reference Dr. Henry Schuver Schuver.Henry@epa.gov
Shell Global and Contaminated Sites Approved Professional Society in BC	Principal researcher for development of guidance and toolkits on monitored natural attenuation (MNA) and natural source zone depletion (NSZD) of petroleum hydrocarbons. The guidance presents a tiered approach to investigation of MNA and NSZD including tools and statistical methods for monitoring of plume stability and strategies for more cost effective monitoring. New tools are presented for measuring NSZD rates including the oxygen gradient, CO_2 efflux and temperature methods. Nomographs are presented for rapid estimation of loss rates through dissolution and biodegradation. Advanced analytical and numerical models for fate and transport modelling of source depletion and plume migration are reviewed and guidance on model inputs is presented.
U.S. Department of Defence Strategic Environmental Research and Development Program (SERDP)	Expert reviewer and advisor for soil vapour intrusion (VI) research projects (mass flux, soil gas remediation optimization, passive sampling, ASU research house). Advisor for prioritization of multi-million dollar research program and identification of innovative research that will meet future needs of the US Department of Defence. (2014-2016).
U.S. EPA OUST	Principal researcher and author of report for project involving development of empirical database and review and application of modelling studies for evaluation of screening criteria for petroleum hydrocarbon vapor intrusion. Assembled data from over seventy sites and developed novel data analysis methods for interpretation of vapour attenuation based on statistical parameters of key site conditions. On the basis of the analysis, an inclusion distance approach was developed as part of a first tier screening approach (2011-2013).
American Petroleum Institute (API) Ethanol-blended fuel research	Project director for research on lead scavengers (ethylene dibromide and 1,2-dichloroethane) involving comprehensive review of studies on groundwater fate and transport and empirical data on vapour intrusion (2015-2016).
American Petroleum Institute (API) Ethanol-blended fuel research	Project director for research on subsurface fate of ethanol-blended fuels, with primary focus being potential for methane generation and enhanced soil vapour intrusion into buildings and 1D and 2D numerical model simulations using the MIN3P-DUSTY code. Provided oversight to novel bench-scale tests of methane generation conducted by the UBC. Provided technical review of technical papers and guidance document (2011-2015).
Shell Global "Cold Climate" Vapor Intrusion Research	Project director for research of vapor intrusion in cold climate areas. Together with Arizona State University (ASU) (Dr. Paul Johnson, Dr. Paul Dahlen), designed and then implemented field program at a house overlying petroleum fuel contamination at site in Saskatchewan, Canada. High resolution monitoring

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Project Canada	of subsurface oxygen, pressure, temperature, soil moisture was conducted, and weather data was obtained to evaluate seasonal trends. The field program was supplemented by a modeling study using 1-D analytical models and multi-dimensional numerical model (MIN3P) developed by the University of British Columbia (2010-2014).
Electric Power Research Institute (EPRI) Research Project US	Dr. Hers is project director for multi-year research project of vapour intrusion at MGP sites. The first phase of the project was a comprehensive review of state of the practice for vapour intrusion, identification of issues for vapour intrusion assessment at MGP sites and development of detailed work plan for field investigation and two sites and complementary laboratory testing program. The second stage consisted of detailed monitoring at two sites and implementation of standard and novel techniques for soil vapour intrusion assessment including passive and active soil gas survey, forensic analyses, detailed monitoring of fate and transport, biodegradation and influence of environmental factors (capping, soil moisture, temperature, etc.) on soil vapour intrusion. The third phase consisted of updating of best practices for assessment of vapour intrusion at MGP sites (2007-2009).
Health Canada – National Vapour Intrusion Guidance and Model Canada	Project director for development of screening level risk assessment guidance for soil vapour intrusion into buildings for Health Canada. A comprehensive screening framework was developed consisting of preliminary qualitative screening to assess potential risks and identification of low, medium and high risk sites, followed by quantitative screening involving use of vapour attenuation factor charts. Novel adjustments were incorporated in the guidance based on groundwater mass flux, bioattenuation and source depletion. The guidance also included supporting information on partitioning, transport and risk equations, and protocol for soil vapour sampling and analysis. As a follow-up to this project, a computer model was created to implement the Health Canada guidance. Follow-up models for site-specific implementation of Johnson and Ettinger model and bioattenuation are in-progress (2004 to 2007).
Health Canada – National Site Characterisation Guidance Manual Canada	Project director for comprehensive guidance manual on site characterisation of contaminated sites, to be used across Canada in support under the Federal Contaminated Sites Action Fund (FCSAP). This manual provides state-of-the-science guidance on contaminated site assessment process, conceptual site model development, sampling design, data quality and detailed methods for investigation of different media (soil, groundwater, soil vapour and indoor air). The manual describes requirements for different investigation phases and how to ensure that representative, high quality data is obtained to fulfil relevant objectives (initial site characterization, risk assessment, remediation planning) (2006-2008).
Health Canada – Site Assessment Training Course Canada	Project director for development of two-day training course for Health Canada as part of their mandate to provide expert support under the Federal Contaminated Sites Action Fund (FCSAP). This course targeted to risk assessors and covered the fundamentals of conceptual model development, hydrogeology, and contaminant transport and site characterisation methods. (2005)

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Health Canada – Physical-Chemical Parameter Database
Canada

Project director for database of physical-chemical parameters and toxicity reference values (TRVs). Reviewed and compared physical-chemical properties from a number of different sources and for selected chemicals, conducted more in-depth assessment of issues for selected chemicals including variability in reported physical-chemical properties and reliability of different literature sources (2005).

Health Canada – Evaluation of Particulate Matter in Indoor Air
Canada

Project reviewer for literature search and initial evaluation of data on particulate matter in indoor air to support development of guidance on human health risks associated with particulate. Helped develop protocol for evaluation of data based on different indoor environments, particulate matter fractions (*e.g.,* PM10, PM2.5), and methods for characterizing particulate matter. Particulate matter data was compiled and statistical analysis conducted to evaluate trends in data. (2004 to 2005).

U.S. EPA Vapor Intrusion Guidance
Washington, D.C.

Dr. Hers was one of three principal authors of the Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway, prepared for U.S. EPA as part of the RCRA Environmental Indicator (EI) program (2001), and was contributing author to the subsequent Draft USEPA VI Guidance (2002). This project included evaluation of available model frameworks, screening-level computer models, and empirical data in support of the development of guidance. In addition, modeling was performed to evaluate volatilization of chemicals from groundwater, develop diffusion and advection parameters, for various U.S. SCS soil texture types, for input into the model (2001-2002). In 2002 and 2003, Dr. Hers helped develop the framework and modeling in support of the vapor attenuation factors (“alpha charts”) incorporated in the Draft EPA OSWER Vapor Intrusion Guidance. In 2003, Dr. Hers one of two experts (the other was Dr. Paul Johnson) retained to respond to comments on OWSER guidance. At this time, he also provided input and review of USEPA Superfund Johnson and Ettinger model inputs. Between 2004 and 2008, Dr. Hers provided data analysis and expert review for development of supporting technical documents and databases on vapour intrusion. A significant focus of his work has been the use of empirical attenuation factor data compiled from over 40 sites to improve understanding of this pathway and guidance. Recent activities have included review of conceptual site models, numerical model simulations and background data (2001-2010).

U.S. EPA Vapor Intrusion Workshops
San Francisco, Dallas, Atlanta

Dr. Hers was an invited speaker at three training workshops on the USEPA OSWER “One Agency” Subsurface Vapor Intrusion Guidance (follow-up to RCRA). His presentation addressed the estimation of input parameters for soil vapour intrusion modeling purposes, and process and inputs used to derive the semi-site specific attenuation factors in the Guidance. His work was foundational both in terms of developing the approach and attenuation values subsequently adopted. (2002-2003)

Alberta Environment
Alberta

Technical advisor for research project on sources of chloroform at affected sites in Alberta. Golder evaluated sources of chloroform from contamination and transformations from chlorinated water, conducted fate and transport modelling, evaluated background sources of chloroform in indoor and assembled groundwater and soil vapour data. From these data, Golder identified possible approaches to management of chloroform as part of contaminated land assessment and remediation (2013).

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Alberta Environment Alberta	Principal researcher and developer of guidance manual for Alberta Environment on assessment of soil vapour intrusion. This manual will include comprehensive guidance on conceptual model development, field data collection, use of predictive models, indoor air assessments and mitigation systems (2006-2007).
BC Ministry of Environment – Development of Standards for High Density Land use Canada	Principal researcher for project involving development of recommended environmental standards for proposed new high density land use category in British Columbia. Conducted survey of similar standards in other jurisdictions, defined a generic high density land use scenario, and developed a framework for development of soil, groundwater and soil vapour standards. For the soil vapour intrusion pathway, conducted research on building characteristics associated with high density land use including underground parking garages and typical ventilation rates and other factors affecting vapour intrusion. The project outcome for the vapour intrusion pathway was a less conservative methodology for establishing vapour attenuation factors (2012).
Science Advisory Board of British Columbia - Guidance on Site Characterisation for Evaluation of Soil Vapour Intrusion Canada	Project director and principal researcher for development of guidance on characterizing sites for evaluation of soil vapour intrusion into buildings. This project focused of providing guidance on soil vapour sampling and analysis, which is emerging in important tool for vapour intrusion evaluation. All facets of soil vapour characterization were addressed including the conceptual site model, vapour sampling design and factors influencing vapour concentrations, soil gas and subslab gas probe installation, sampling methods, and field and analytical procedures (Summa canisters, sorbent tubes, passive samplers). To complement the soil vapour guidance, recommendations for characterization of other media (soil, groundwater and indoor air) were also provided as well as ancillary testing to better evaluate conditions for vapour intrusion (*e.g.,* building conditions) (2005 – 2006, update 2010).
Science Advisory Board of British Columbia - Hydrological Assessment Tools Project Canada	Project director and principal researcher for project involving development of hydrogeological assessment tools for risk assessment of contaminated sites. This project included three separate components (i) a protocol for evaluating the mobility of light non-aqueous phase liquid (NAPL), (ii) a study on methods and approaches for evaluating the fate and transport of chemicals within the unsaturated zone, and (iii) approaches for evaluating influence of vertical aquitards on contaminant mobility. Each of these projects identified the state of the science pertaining to the technical issue (theory, models and practice), followed by practical guidance on how concepts could be used by practitioners to better assess contaminant fate and transport, as part of a site specific risk assessment process (2005 and 2006).

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Science Advisory Board of British Columbia - CSST Matrix Standards Review Project
Canada

Project director and principal researcher (human health pathways) for project involving review of protocol used to develop matrix soil standards in British Columbia. The matrix soil standards for British Columbia involve consideration of human health and ecological pathways, and were initially developed in 1996. This project involved a 10-year review of the standards, with the aim of identifying new scientific advancements for existing pathway standards, and identifying new exposure and receptors that should be considered. Highlights of the project included evaluation of the four-compartment groundwater model (leaching, unsaturated zone transport, mixing and saturated zone transport), and in particular, methods for evaluating metals partitioning and transport (leaching tests, geochemical modeling), (ii) review of recent developments for assessment of soil vapour intrusion and recommendation of a modeling approach to development generic and semi site-specific standards, (iii) development of a framework and preliminary protocol for deriving standards for two new land uses (high density urban and wild lands) and (iv) updating of the input assumptions and protocol for estimating dose rate and risks for ingestion, dermal contact and dust pathways (2005).

Ontario Ministry of Environment
Ontario

Project reviewer and advisor for state-of-the-science guidance on soil vapour and indoor air testing developed for Ontario Ministry of Environment. The conceptual site model, process, methods and interpretation of results were discussed in detail. Supporting data on such aspects as site conditions and environmental factors influencing soil vapour, and building conditions and background sources influencing indoor air quality were included. Review of models for prediction of vapour intrusion from soil, groundwater and soil vapour sources. Development of screening level modeling approach incorporating bioattenuation reduction factors for petroleum hydrocarbon compounds. Review of Ontario MoE Tier 1 and 2 process including soil depletion multiplier model and groundwater model (2005-2009, update in 2011 and 2012).

New Jersey Department of Environmental Protection
New Jersey

Dr. Hers is the principal researcher for a multi-year research project of subsurface vapour intrusion into buildings for the New Jersey Department of Environment Protection. This project has involved detailed testing of media concentrations and building properties to assess vapour intrusion at four sites (two petroleum hydrocarbon and two chlorinated solvent sites). Extensive and innovative testing procedures involved the use of tracers, cross-slab pressure monitoring devices, multi-level probes for profiling, subslab probes and groundwater monitoring using geoprobe and diffusion bag sampling. Through this work, better knowledge was obtained in the following areas: (1) vapor attenuation factors for different sites and contaminants, (2) volatilization from the water table and influence of fresh-water lens and capillary fringe, (3) bioattenuation of petroleum hydrocarbon vapours and kinetics for different compounds, (4) subslab vapor sampling, (5) influence of building conditions on vapour intrusion and monitoring methods. The practical outcomes of this work were data and methods that were used to help support the development of the New Jersey vapor intrusion guidance (2002-2006). Dr. Hers was also an invited reviewer of the New Jersey Vapor Intrusion Guidance.

Resumé IAN HERS

Canada Mortgage and Housing Corporation Vancouver, BC	Director for research program for CMHC involving evaluation of potential soil gas intrusion into a building constructed above residual coal tar contamination and dust migration into residences at a metals-contaminated site. The coal-tar site monitoring scope included testing of sump water, groundwater, soil gas, sump air and indoor air samples, and monitoring of building depressurization. Golder also developed and then implemented an innovative tracer test using helium to measure soil gas flow rates. The study concluded that the risk assessment findings were valid based on follow-up monitoring (2002-2003).
BC Environment Training Courses British Columbia	Co-director and coordinator of comprehensive two-day and four-day courses were developed for BC Environment staff. The objective of the course was to provide participants with fundamental principles, concepts and methods for the characterization and remediation of contaminated sites. The course included a one-day field component where various field methods (drilling, well installation, groundwater sampling, vapour sampling, air sampling) were demonstrated. (2004).
Michigan Environmental Science Board Lansing, MI	Provided expert testimony to the Michigan Environmental Science Board on the use of the vapour intrusion models to predict indoor air quality. The testimony scope included use of the Johnson and Ettinger model, and appropriate input parameters (2000).
State of Michigan Industry Group Michigan	Expert review of issues pertaining to vapour intrusion pathway including validation and use of vapor intrusion models, review of empirical data on vapour intrusion, evaluation of regulatory frameworks and models used by different regulatory jurisdictions, and recommendations for assessment and regulation of this pathway conducted for a consortium of four large companies in the State of Michigan (2000 and 2001).
UK Environmental Agency – Soil Gas Models United Kingdom	Advisor for research and guidance development project for evaluation of soil gas intrusion models. Reviewed ten different soil gas models (Johnson-Ettinger, Jury, VAPEX3, Unocal, GSI, BC, VOLASOIL, BPRISC, Ferguson model) and conducted sensitivity analysis and provided recommendations on models for use in UK regulatory environment (1999-2001).

PROJECT EXPERIENCE – LNAPL MANAGEMENT

CN Biggar Site, Saskatchewan	Senior technical advisor and reviewer for LNAPL management strategy for large LNAPL release at former railyard site in Saskatchewan. The review involved consideration of the LNAPL conceptual site model and lines of evidence for stability of the LNAPL body including monitoring data at wells, product recovery data, hydrostratigraphic data, and transmissivity data (2016).
BC Ministry of Environment	Principal researcher for development of LNAPL guidance for BC Ministry of Environment. Developed a threshold approach to identifying potentially migrating LNAPL based on soil type and LNAPL thickness as step for site screening combined with novel application of observational data and other lines of evidence including laboratory data and modelling to assess potential LNAPL mobility.
Imperial Oil Ltd. Ioco Refinery, BC	Technical reviewer for assessment and remediation of LNAPL and dissolved plumes for large refinery with twelve 12 different areas of concern, some of which are directly adjacent to Burrard Inlet. Developed novel approach for assessment and prioritization of LNAPL management through monitoring, field transmissivity and laboratory testing approach for evaluation of LNAPL stability.
CP Rail Yard Revelstoke, BC	Project director responsible assessment of large diesel release, LNAPL recovery and stability, MNA of dissolved plume, and regulatory liaison and reporting. An application for re-classification to non-high risk based on stable LNAPL is in pr
ExxonMobil LNAPL Research Project and Guidance	Principal researcher for research program on LNAPL mobility and recovery for Torrance Refinery. Developed program for field testing including LIF, transmissivity testing and laboratory testing including capillary and other specialized parameters. Analyzed different types of data to develop better understanding of effectiveness of different line of evidence. Also developed tiered LNAPL mobility assessment guidance.
ITRC LNAPL Guidance	Key member of workgroup that developed guidance. Developed and continues to deliver internet based training.

PROJECT EXPERIENCE – RISK ASSESSMENT AND VAPOUR INTRUSION ASSESSMENT

Vapour Intrusion Assessment and Human Health Risk Assessment, Alberta Environment, Calgary, AB	Project director for evaluation of soil vapour intrusion and human health risk assessment in residential area with subsurface creosote impacts. Conducted review of historical information from various sources, developed updated conceptual site model for geological conditions and distribution of DNAPL, groundwater and soil vapour, and designed and implemented investigation program focused on evaluation of shallow groundwater and soil vapour impacts. Monitoring conducted indicated DNAPL sources below the water table, possibly controlled by bedrock topography, but mostly dissolved impacts in shallow groundwater. Creosote-related concentrations in soil vapour were evaluated through vertical profiles. The human health risk assessment focused on soil vapour intrusion to indoor air pathway. Responsible for design and implementation of indoor air quality monitoring program in multiple house (2010-2014).

Health Canada and DND – Valcartier Vapour Intrusion Study
Québec

Project director for evaluation of soil vapour intrusion at site with large chlorinated solvent plume. Reviewed existing data, conducted predictive modeling and developed work plan. Provided oversight of all field monitoring activities, quality control, and data validation and interpretation (2006-2009).

IBM Vapour Intrusion Assessment
San Jose, CA

Expert advisor and reviewer for design of soil vapour monitoring study to evaluate potential vapour intrusion risks from chlorinated solvent plume at former industrial site. Developed protocol for quality control testing and soil gas performance testing, including evaluation of methods for evaluating soil-air permeability (2006).

Vapour Intrusion and Air Quality Assessment and Mitigation
Calgary, AB

Expert advisor and reviewer for comprehensive study of indoor air quality in homes above large chlorinated solvent (TCE) plume in groundwater. Responsible for review of hydrogeological data, evaluation of soil vapour fate and transport and predictive modeling, and design of soil vapour and indoor air monitoring program including all quality assurance/quality control aspects. Developed criteria for indoor air assessment and risk management measures. Coordinated input from other consultants on the technical review team and presented findings to senior management and regulatory agencies. Led soil vapour mitigation program from design, pilot and diagnostic testing, construction and post-construction monitoring involving installation of subslab depressurization (SSD) and submembrane depressurization (SMD) systems at over 60 residential buildings and school. (2002 - 2006).

Confidential Client
British Columbia

Project director for site assessment and remediation feasibility study for groundwater impacted by ammonia sulphate and metals. A comprehensive evaluation of remedial options was conducted, including an innovative modelling assessment where interaction between groundwater and a large river was assessed, followed by development of a remedial plan and conduct of pilot test involving groundwater pump and treat. In one area, the groundwater plume underlies a small community, and therefore a vapour intrusion assessment was conducted, which involved initial characterization of groundwater and soil vapour and modelling, followed by indoor air monitoring. A multiple lines of evidence approach was followed, and isotopic testing was conducted to support assessment of possible background ammonia sources.

Law Firm
United States

Retained by legal counsel to provide expert review of exposure and health risk arising from potential vapor intrusion into planned future building at site contaminated with chlorinated solvent compounds. Conducted hydrogeological evaluation and assessment of chemical transport in groundwater in fractured bedrock setting, and reviewed predictive modeling of soil vapor transport and intrusion in building. Conducted comprehensive review of exposure factors and compared deterministic risk assessment results to probabilistic assessment using Monte Carlo simulation and Crystal Ball. Reviewed soil vapor sampling and analysis methods and results (2002).

Retained by legal counsel to provide expert review of exposure and health risk arising from potential vapor intrusion into planned future building at site contaminated with chlorinated solvent compounds. Conducted hydrogeological evaluation and assessment of chemical transport in groundwater in fractured bedrock setting, and reviewed predictive modeling of soil vapor transport and intrusion in building. Conducted comprehensive review of exposure factors and compared deterministic risk assessment results to probabilistic assessment using Monte Carlo simulation and Crystal Ball. Reviewed soil vapor sampling and analysis methods and results (2002).

Confidential Client
Groundwater and Soil Vapor Assessment
United States

Project manager and technical reviewer for soil gas risk assessment conducted at industrial research facility. Releases of a wide-range of chlorinated solvent compounds have affected soil and groundwater concentrations below and adjacent to buildings at the site, which included a large generator room and nearby offices. Using available soil and groundwater data, a site-specific risk assessment was conducted, and risk-based screening criteria were developed. The geological setting consists of residuum underlain by groundwater, and is complicated by sub-surface utilities and foundations. Through appropriate use of a screening level model for predicting indoor air concentrations and careful consideration of soil properties, characteristics for different buildings, and receptor characteristics, it was shown that risks to workers in the building would likely be acceptable (2002).

Resumé IAN HERS

Confidential Client
Calgary, AB

Conducted expert review of soil gas assessment conducted at large infilled industrial site with elevated methane levels proposed for re-development. Subsequently implemented field investigation program to evaluate possible sources of methane, which included site fills, underlying bedrock and adjacent landfills. Field program included multi-level soil gas sampling and dissolved gas testing and stable carbon isotope testing to help identify methane sources. Evaluation of conceptual remediation measures to address possible gas control measures (2003-2004).

Alberta Environmental Protection
Calgary, AB

Retained to conduct expert third-party review of site assessment, risk assessment and remedial options for the Lynnview Ridge site in Calgary, Alberta. Several hundred houses were constructed on a former refinery site and thus site characterization (soil vapour sampling), estimation of potential vapour intrusion into houses, indoor air testing and vapour intrusion mitigation were important issues for this site (2003-2004).

BC Hydro
Hazelton, BC

Technical advisor for evaluation of vapour intrusion issues for houses located above a diesel contaminated groundwater. Designed soil vapour sampling program, which included the collection of split samples using Summa canisters (EPA Method TO-15) and sorbent tubes. Responsible for predictive modeling of potential vapour intrusion into indoor air (2001).

CN Rail Richmond Hill, ON

Technical reviewer of site characterization report and risk assessment for light oil spill that had migrated below a townhouse complex. At several units, oil had migrated into building drains. Reviewed potential mechanisms for vapour intrusion and results of indoor air monitoring. Provided recommended mitigative strategies for addressing vapour intrusion pathway (2001).

Yukon Pipe Line
Whitehorse, YK

Project manager for development of risk-based remediation standards for 40 hectare former tank farm site contaminated with gasoline and diesel from approximately 32 large above-ground tanks that leaked. Residential development is planned for this site. Following remediation of shallow contaminated soil, risk-based standards were used to identify requirements for deeper contamination with the primary potential exposure pathway of concern being vapour intrusion. Extensive monitoring of soil vapour was conducted at this site, which included testing to evaluate lateral and vertical vapour attenuation from hydrocarbon sources, and seasonal variation in vapour concentrations. Predictive modeling was conducted to evaluate vapour fate and transport, and potential intrusion into buildings. Risk based standards were developed for vapour and soil for both individual chemicals (BTEX and naphthalene) and TPH fractions. The risk based standards approach was to identify safe off-set distances for residential development and identify areas of the site that could be developed without further in situ remediation (2000-2001).

Shell Oy
Kokkola, Finland

Prepared risk-based remediation plan for site contaminated with light fuel oil and diesel. Residual hydrocarbon had migrated below a rail yard, and the dissolved hydrocarbon plume was near to a park and daycare centre. Evaluated site characterization data, conducted groundwater modeling (BIOSCREEN), soil vapor transport and intrusion modeling, and evaluated natural attenuation mechanisms. Developed risk based cleanup levels for the source zone, and a protocol for evaluating natural attenuation mechanisms at this site (2000).

Resumé IAN HERS

ADI Footscray Victoria, Australia	Evaluated soil vapour fate and transport, and conducted predictive modeling for site contaminated with chlorinated solvents (TCE, DCE, VC), for which residential land use was planned. Site geology consists of thin veneer of fill and unconsolidated soil deposits above basalt deposits. Soil vapor data suggested that barometric pumping was resulting in relatively high advective flux of soil gas and hence vapor transport rates. Assisted with the conceptual design of engineering controls (capping, ventilation) to address potential vapor intrusion risks (1997).
BC Environment, AEP, API, CPPI British Columbia	Project manager for research project involving experimental design, implementation, and modelling conducted to assess predictive model of soil gas VOC transport and intrusion into buildings, required to validate risk based methods for the soil gas to indoor and outdoor air pathways. Developed methods for soil gas analysis, construction, and testing of flux chambers and testing of experimental building. (1996-1997).
IBI Group Vancouver, BC	Project manager for remediation planning, human health and ecological risk assessment for two industrial sites. Former land uses included railway yard and foundry. The risk assessment involved a Problem Formulation followed by quantitative risk estimation for the soil ingestion, dermal adsorption, and inhalation (dust and volatiles) pathways. The remedial plan included a Special Waste Reduction Plan in which remedial technologies were evaluated in terms of feasibility and cost (1996).
Human Health Screening Risk Assessment Burnaby, BC	Advisor for project involving a screening-level human health risk assessment at a commercial site where chlorinated solvents were encountered in soil and groundwater. A soil gas infiltration model was used to estimate outdoor and indoor exposure to vinyl chloride in air, and lifetime cancer risks were estimated for a commercial receptor. Responsible for design of indoor air sampling program (1995).
Chinese Merchants Association - Murrin Site Vancouver, BC	Task leader for a quantitative human health risk assessment for inhalation exposure at a coal tar contaminated site. The assessment consisted of a deterministic screening risk assessment and a detailed probabilistic risk assessment for benzene, which was the contaminant of primary concern. To mitigate risks, an impermeable liner and soil vapour ventilation system were subsequently designed and installed (1994).
Chatterton Petrochemical Delta, BC	Task leader for soil gas and hydrogeological modelling of BTEX migration and attenuation at a former petrochemical site. Subsequently, risk-based remediation criteria (RBRC) were developed. The RBRCs were based on protection of human health and environment (aquatic) for several potential exposure pathways and included a quantitative risk assessment (1995).
Mid-Van Developments Ltd. Vancouver, BC	Assisted in conducting a risk assessment for a site contaminated with fuel oil leaking from a UST. Project Manager for the design and installation of a vapour management system (VMS) (1995).
Telesat Canada Vancouver, BC	Project manager for a supplementary investigation and human health and ecological risk assessment for an industrial site in Vancouver, BC (1995-1996).

Resumé IAN HERS

Canada Mortgage and Housing Corporation Canada	Technical advisor for project involving an assessment of the practice of site-specific human health risk assessment for contaminated sites. Assisted in preparation and evaluation of (i) questionnaire sent to risk assessment practitioners and (ii) round-robin hypothetical case study. Assessed risk assessment methodology and conducted statistical evaluation of results (1996).
Development of Risk-Based Remediation Criteria British Columbia	Assisted in the development of framework and protocol for derivation of risk-based remediation criteria for petroleum hydrocarbons protective of human health and the environment. Reviewed existing regulations, analytical methods, petroleum composition and toxicology, and environmental fate and transport models for petroleum hydrocarbons, including models for soil vapour intrusion into buildings and outdoor air. Helped develop framework for establishing new matrix soil quality criteria for BC Environment (1995).
GVRD - Coquitlam Landfill Risk Assessment Coquitlam, BC	Project manager for human health and ecological risk assessment for the Coquitlam Landfill, which included detailed site investigation, fate and transport modeling for leachate from fly ash, bottom ash, biosolids and refuse, quantitative human health risk assessment and development of risk management measures (1995 and 2001).
Manufacturing Site Richmond, BC	Conducted review of VOC data and human health risk assessment for site used for manufacturing of airplane components. Review of vapour management system (VMS) used to mitigate VOC migration (1995-1996).
Manufacturing Site Burnaby, BC	Project advisor for risk assessment of former manufacturing site contaminated with chlorinated solvents. Designed and implemented field program, and conducted exposure modelling for soil gas modelling. Assessed natural attenuation mechanism for chlorinated solvents in groundwater, and provided recommended risk management measures (1997).
GVRD - Biosolids Assessment Coquitlam, BC	Project manager for assessment of leaching potential of a biosolid and soil landfill cover, and potential effects on adjacent creek (1997).
City of North Vancouver North Vancouver, BC	Project manager for focussed risk assessment of potential effects of hydrocarbon-contaminated soil on aquatic life in creek. Involved hydrological modelling, steamflow assessment, and assessment of potential ecological risk through narcosis approach (1997).

PROJECT EXPERIENCE – SOIL GAS/LANDFILL GAS ASSESSMENT AND MITIGATION

Resumé IAN HERS

INAC and Nak'azdli Whut'en First Nation
Fort St. James

Technical director for review of site investigation data and design and specification of vapour management system for school at petroleum hydrocarbon contaminated site. Conducted value-engineering assessment and developed innovative approach for vapour mitigation involving sealing of ducts with spray-applied sealant combined with passive venting. Responsible for development on commissioning and monitoring program (2014-2016).

Mitigation of TCE Vapour Intrusion SSD
Vancouver

Technical director for assessment and mitigation of TCE intrusion at retail complex. An innovative approach using onsite HAPSITE GC/MS was deployed to characterize pathways, and complementary testing of pressures were used to assess vapour intrusion potential. Highly elevated indoor TCE concentrations were measured requiring removal of workers and rapid response for soil vapour mitigation. Worked closely with Golder's construction group, who installed subslab depressurization system consisting of multiple sumps, fan and controls for remote notification of system operation and sealed floors. The system was installed, commissioned, and indoor air tested (with significant reduction observed) and retail store was re-occupied within one week of measuring elevated concentrations. (2015)

WSP Canada Ltd. Soil Gas Mitigation New Building
Richmond, BC

Project director for design, specification, and quality assurance test program for sub-slab passive vapour mitigation system for a new slab-at-grade three storey fire hall. Mitigation which consisted of Liquid Boot liner and vents was required because of residual petroleum hydrocarbon contamination in soil. (2016)

Northern Health Radon Mitigation SSD
Prince George, BC

Project director for design, specification, tendering, construction oversight and post-mitigation monitoring of subslab and submembrane depressurization system to address elevated indoor radon concentrations at two residential care homes. (2015)

Mitigation of Petroleum Hydrocarbon Vapour Intrusion
Hazelton, BC

Project director for design, specification, tendering, construction oversight and post-mitigation monitoring of subslab depressurization system to address elevated indoor petroleum hydrocarbon at church. Included sump and dewatering system to address shallow water table (2016).

Cambridge Site Mitigation of TCE New Building Aerated Floor
Cambridge, Ontario

Project director for 4,000 sq. meter commercial building overlying large (community-scale) trichloroethylene plume in shallow groundwater. Given relatively high concentrations, an active mitigation system was designed comprised of aerated floor connected by risers to two 150 Watt roof-top radon-type fans. Conducted modelling using Modified Johnson and Ettinger Model and specified performance requirements for air flow and vacuum based on venting requirements, followed by detailed design of fans and control and alarm systems, and monitored construction and commissioning of the system. Monitoring to-date indicates acceptable system performance. (2014)

Confidential Client Vapour Intrusion and Air Quality Assessment and Mitigation TCE Site
Calgary, Alberta

Technical director for comprehensive evaluation of indoor air quality in homes above large chlorinated solvent (TCE) plume in groundwater. Testing was completed multiple times in over 600 homes. Led soil vapour intrusion mitigation program from design, pilot and diagnostic testing, pressure monitoring, construction, quality assurance testing and post-construction monitoring involving installation of subslab depressurization (SSD) and submembrane depressurization (SMD) systems at over 60 residential buildings and school. Assisted with communications to stakeholder groups. (2002 - 2007).

Resumé IAN HERS

Trans Canada Pipeline Gas Emissions Assessment
Alberta, BC

Project director for assessment of possible sources of soil gas emissions observed along pipeline in bog area. The assessment consisted of collection and analysis of gas samples obtained from the pipeline, shallow probes, and surface emission flux chambers, and analysis for fixed gases and stable carbon isotopes through University of Alberta. Evaluated possible biogenic versus thermogenic sources of gas through fixed gas ratios and stable carbon isotope ratios. Concluded that the likely source of gas observed was shallow bog deposits (biogenic source) and not from the pipeline (2010).

Arbour Lake School District
Calgary, Alberta

Project director for project involved assessment and conceptual design of mitigation measures for fill site with methane impacts. The site had historically been used for disposal of fills containing manure and organic material. The assessment consisted of a detailed soil gas survey, measurement of gas pressures and gas flow rates. Gas Screening Values were estimated (based on UK guidance) using methane concentrations and soil gas flow data to determine semi-quantitative estimate of risk. The site area was divided into different areas based on risk classification and conceptual evaluation of passive/active mitigation was completed (2009-2010).

Major Oil Company
Alberta

Project director for assessment of potential risks associated with abandoned wells and potential soil gas issues at two sites. The work included review of existing data on forensics and potential sources of gases present, conducting shallow soil gas surveys, development of conceptual site model, assessment of well mitigation strategies and gas generation rates, mathematical modeling of subsurface gas migration below and above water table using multiphase reactive transport numerical model (COMPFLOW), coupling of predicted fluxes with air dispersion model (2009-2010).

Gateway Program (Ministry of Transportation) Gas Controls and Fire Protection Management Plan
Delta, BC

Technical director for major project involving construction of highway and large weigh scales through five demolition, land clearing and construction (DLC) landfills and peat bog deposits as part of the South Fraser Perimeter Road in Delta, BC. Responsible for the design of the landfill gas investigation program, assessment and prediction of gas generation and design of passive and active gas controls. Given that the landfills are constructed of woodwaste and major excavations are planned, an important component was preparation of a plan for fire prevention, preparation, monitoring and mitigation (2009-2011).

Whistler Athlete's Village Gas Mitigation System
Whistler, BC

Project director for design of gas mitigation system for portion of athlete's village located next to a former municipal solid waste landfill. The buildings that were mitigated were a lodge and townhouses. A passive venting system and barrier was designed with a monitoring system that included alarms in the basement and crawlspaces of buildings. Due to the numerous utility penetrations and non-uniform foundation, a flexible geomembrane (30 mil PVC) was chosen as the barrier layer. Golder was responsible for construction quality control testing and post-construction performance monitoring (2008-2009).

Resumé IAN HERS

Orica-Goodman Development Site, Botany Bay Sydney, Australia	Project advisor and reviewer for soil gas review and conceptual design of mitigation for major commercial development (about 18 buildings and warehouses) at a site with extensive filling in a low-lying peaty area, which was also highly contaminated with chlorinated solvent chemicals. Vapour intrusion modeling of buildings with various types of mitigation systems was initially conducted. Next, a number of different mitigation strategies were evaluated as to feasibility and effectiveness including passive venting system, wind-turbine assisted venting systems and active venting systems. Several different geomembranes were evaluated as to their constructability and vapour transmission properties. Through the engineering options analysis, a venting design involving use of low energy requirement fans was chosen since it provided for more reliable performance than a wind-turbine system or passive system, and also pipe spacing to be increased (2008-2009).
Large Distribution Warehouse and Office Complex Surrey, BC	Project director for site assessment, design, inspection and post-construction monitoring at site with extensive woodwaste and peat deposits and biogas (methane) production. Designed liner system consisting of liquid-boot spray-applied membrane below office building and 15 mil polyolefin (taped) liner below warehouse, which was appropriate for warehouse area given high ventilation and dilution in this large warehouse structure. Vents were connected to 12 wind turbines. Post-construction monitoring indicated that the system was working with relatively low methane concentrations below the building (2008-2009).
Pacific Place Condominium (former Expo 86 Site) Vancouver, BC	Project director for health and safety monitoring and gas mitigation at site along False Creek in Vancouver, BC. During site development excavations, strong hydrogen sulphide odours were noted, which emanated from marine deposits under reducing conditions where hydrogen sulphide was being generated. Golder was retained to conduct monitoring program and develop health and safety protocols, and then design mitigation measures for the condo. The measures were a passive (but provisionally active) venting system below a sealed foundation slab. In areas where there were penetrations of the slab (sumps, utilities), special sealing provisions were specified including geomembranes in local areas (2008).
Cedar Grove Development Site Victoria, BC	Project director for review of existing site assessments, gap analysis, soil gas monitoring program, and design of passive mitigation system with geomembrane barrier for fill site underlain by peat deposits developed for commercial development (2008).
Petroleum Contaminated Site Melbourne, Australia	Reviewer of active venting system and barrier system for building to be constructed at site with extensive petroleum contamination. Helped create computer program for soil venting design (2006).
GVRD - Coquitlam Landfill Gas Coquitlam, BC	Project manager/director for multi-year project involving landfill gas monitoring program, shallow soil gas survey and assessment of methane landfill gas emissions for input into human health risk assessment, landfill gas generation study, assessment of existing landfill gas extraction system, design and construction oversight for upgraded active landfill gas extraction system (20 new wells and header), design of passive methane collection system below road and perimeter landfill gas monitoring network (1995 - 2006).

Resumé IAN HERS

Andy Livingstone Park – Methane Venting and Control System Andy Livingstone Park – Methane Venting and Control System	Advisor and reviewer of active methane venting system constructed below existing building constructed above extensive woodwaste and creosote contaminated soils. Design of piping, blower, monitoring and instrumentation system (2004 to 2005).
Large Fill Site – Methane Evaluation Calgary, AB	Project manager for evaluation of elevated methane levels at large site with extensive organic fill deposits where residential development is proposed. Reviewed site characterization, biological methane potential tests, gas production and pressure data. Implemented additional program of testing and analysis (dissolved gases, isotopes) to identify potential biogenic and thermogenic methane sources (fill, underlying bedrock, adjacent landfill). As part of preliminary feasibility study, identified possible remedial strategies based on proposed development (2003).
Discovery Park - Methane Venting and Control System Vancouver, BC	Reviewer of design of methane control system for site constructed above organic silts and peats. Design is for passive venting that can be converted to active system and partial geosynthetic barrier. Reviewed design of piping system below and through building and soil gas monitoring system (2001).
CMA Murrin Site Vancouver, BC	Project manager/director for soil vapour assessment, human health risk assessment, design and construction management of soil gas venting system, and on-going monitoring at site with high levels of coal-tar contamination developed for commercial use (1993-2006).
Pemcor Developments - Methane Venting and Control System Vancouver, BC	Project engineer for design for subsurface soil gas venting and control system installed below building construction at former industrial landfill in Vancouver, BC. (1995)
City of Burnaby - Methane Venting and Control System Burnaby, BC	Project engineer for subsurface soil gas venting and control system installed below building constructed adjacent to a former Stride Avenue landfill in Burnaby, BC. (1995)
Mid-Van Developments - Methane Venting and Control System Vancouver, BC	Project engineer for subsurface soil gas venting and control system installed below building constructed on peat soil deposits. (1995)
Truck Manufacturing Site Burnaby, BC	Soil gas survey used to assess petroleum hydrocarbon and solvent contamination at a former truck manufacturing site (1995).
Gas Station Site Kelowna, BC	Project reviewer for soil gas survey conducted at service station site in Kelowna, BC (1994).
BC Environment – Pacific Place Site Vancouver, BC	Task leader for design and implementation of soil gas surveys for delineation of the extent of contamination and input into soil gas modeling and human health risk assessment (1993).
Solvent Sites Vancouver, BC	Soil gas survey at two TCE and PCE contaminated sites in Vancouver, BC (1992-1993).

PROJECT EXPERIENCE – ENVIRONMENTAL RESTORATION

FNESS Large Diesel Impacted Sites
Tsay Key Dene and Kwadacha, Northern BC

Senior technical reviewer for site remediation projects in two northern BC communities (Tsay Key Dene and Kwadacha) with large diesel spills. Together with Golder team, evaluated remediation options for enhanced bioremediation technologies, designed and conducted pilot tests (bioventing, product recovery), conducted modeling of LNAPL mobility and recovery, and evaluated natural attenuation of LNAPL sources. Due to a lack of human health and ecological risks, it was concluded that monitored natural attenuation was the most appropriate remediation technology for the site, and a strategy for site monitoring was developed. Senior technical reviewer for remediation reports ensuring that the work met quality expectations and was suitable for submission to regulatory agencies.

Chinese Merchants Association - Coal-Tar Site
Vancouver, BC

Project engineer/manager for site remediation at a former coal gasification plant ("Murrin site"). Project components consisted of conceptual remedial planning, final remedial design, geotechnical design, costing, contract preparation, tendering, and site remediation implementation. Designed and conducted pilot tests, and prepared full-scale design for an active sub-slab soil vapour control system, geomembrane cap, and groundwater and product recovery systems. Assisted with groundwater extraction modeling. Conducted bench-scale and pilot-scale investigation to evaluate methods to stabilize hydrocarbon contaminated soils. Currently managing operation, maintenance and monitoring of system. Responsible for managing all Golder Associates staff, and for liaison with owner, architect, construction manager, and regulatory agencies (1993-2001).

Major Wood-Preserving Facility (Creosote and Chlorophenol)
British Columbia

Prepared remediation plan for large major wood products manufacturing site contaminated with creosote and chlorophenols, which is located along the Fraser River. Coal-tar DNAPL has migrated to significant depths (over 20 m) in some areas, and there is an extensive dissolved hydrocarbon plume. Responsible for evaluation and integration of hydrogeological and contamination assessment, product recovery system, groundwater pump-and-treat system, human and ecological risk assessment, site monitoring and development of risk-based remediation plan (1997-2000).

Multi-national Waste Management Company
Delta, BC

Project manager for design and implementation of soil vapour extraction and bioventing system for varsol contamination. Responsible for SVE/airflow modelling (1996).

BC Environment-Pacific Place Site (Large Industrial Site)
Vancouver, BC

Assisted in the screening of remedial options, preparation of remedial plans, and preparation of excavation and soils management plans at the former Expo '86 site (Pacific Place). The site covers 200 acres of former railway, saw mill, metal shops, coal gasification plants, and dump sites (1988-1992).

Juker Holdings Ltd. – PCB Remediation
Delta, BC

Task leader for design of remedial investigation program used to delineate the extent of PCB Special Waste in soil. Responsible for program implementation and monitoring quality control (1996).

Resumé IAN HERS

Ex situ Bioremediation British Columbia	Project manager for landfarming bioremediation at four petroleum hydrocarbon sites and one coal-tar site. Designed treatment and monitoring programs and evaluated treatability studies. Conducted treatability study for coal-tar contaminated soils evaluating effectiveness of different nutrient amendments including surfactants. Responsible for permitting, regulatory liaison, and on-going soil monitoring. Soil volumes ranged from 200 m3 to 1,000 m3. Project manager for bioremediation treatability study conducted for coal-tar contaminated site in Surrey, BC (1991-2000).
Vancouver International Airport Authority – Ex situ Bioremediation Guidance Document Richmond, BC	Prepared Bioremediation Guidance document for construction and operation of ex situ bioremediation facility. Addressed detailed procedures for soil remediation amendment requirements, tilling, soil moisture management and monitoring (1996).
Contaminated Soil Storage and Treatment Facility Projects British Columbia	Provided design and construction monitoring for contaminated soil storage and treatment facilities including Special Waste contaminated soils. Designed liners, caps, leachate collection systems and sumps, and prepared contract documents. Specific projects include five facilities lined with polyvinyl chloride (PVC) ranging in size from 200 m2 to 1,200 m2 and two facilities lined with high density polyethylene (HDPE) ranging in size from 2,300 m2 to 2,800 m2. Preparation of Monitoring and Contingency Plans for Special Waste treatment facilities (1991-1996).
City of Vancouver "Block 17" Site Vancouver, BC	Prepared specification for handling, testing, and disposal of contaminated soil and groundwater for inclusion in site development tender (1996).
Product Recovery Projects Vancouver, BC	Designed hydrocarbon product recovery wells and trenches and evaluated product recovery systems for a LNAPL site (floating waste oil contaminated with PCB) and DNAPL site (coal-tar) (1993-1994).

Resumé IAN HERS

Contaminated Soil Excavation and Disposal and UST Decommissioning
British Columbia

Completed design, planning, contract specification, contract administration and monitoring of remedial excavations, UST decommissioning, stockpile and excavation sampling programs, contaminated soil disposal, groundwater control, air monitoring at over 25 petroleum hydrocarbon facilities and industrial sites. Six project examples are listed below:

1. Imperial Oil Refinery Site, Port Moody, BC
   Prepared contract and managed field monitoring program for remedial excavations at lead laydown and separator sludge disposal area. Monitoring of backfilling and compaction of excavation (1990).
2. City of North Vancouver, North Vancouver, BC
   Project manager for remedial investigation of former service station, preparation of contract and specifications for UST decommissioning, and contaminated soil remediation (1997).
3. Sawmill Site, Victoria, BC
   Reviewed Phase II investigation data and prepared remediation sampling and excavation plan for chlorophenol contaminated site (1993).
4. UST Site, Burnaby, BC
   Project manager for UST removal and excavation program at site with eight USTs containing a diverse range of fuel products and solvents (1994).
5. Fertilizer Plant, Abbotsford, BC
   Review of contract specifications for remedial excavation and landfill disposal of metals contaminated soils and sediments in ditches (1994).
6. Hazco Environmental Services Ltd., Richmond, BC
   Project manager for monitoring program conducted at three UST sites at a former car rental facility at Vancouver International Airport (1996).

Resumé IAN HERS

In situ Treatment Technologies
British Columbia

Completed over 20 projects involving evaluation, design, implementation and monitoring of groundwater extraction, product recovery, soil vapour extraction (SVE), bioventing, air sparging and bio-sparging systems for in situ treatment of hydrocarbon-contaminated soil and groundwater. Seven project examples are listed below:

1. Dual-Phase High Vacuum Extraction – UST Site, Burnaby, BC
   Task leader for design and implementation of high vacuum dual-phase soil vapour extraction pilot test for relatively deep glacial drift soil deposits contaminated with gasoline. Conducted pilot test that included monitoring of soil gas flow rates and soil vacuum, used to estimated soil-air permeability and radius-of-influence for soil-air flow. Designed full-scale remediation system that included 20 extraction wells and 25 HP high-vacuum dual-phase extraction system, and catalytic oxidation air treatment. Assisted with the preparation of contract specifications, tendering, bid evaluation, system commissioning and monitoring (1996-2000).
2. Soil Vapour Extraction – Service Station Sites, Grand Forks, BC
   Project manager for soil vapour extraction remediation project for hydrocarbon contamination at two adjacent service station sites. Specific responsibilities were assessment of pilot test data, design of piping system, building and soil vapour extraction equipment (*i.e.,* blowers and related equipment), permitting, design of monitoring program, preparation of contract documents, tendering, construction monitoring, and performance monitoring. Also responsible for on-going groundwater monitoring of the hydrocarbon plume and for evaluation of natural attenuation of hydrocarbon (1993-1999).
3. Diesel Spill Site, Hazelton, BC
   Technical advisor for pilot testing (respiration testing) and design of in situ treatment for large diesel spill at hydrogeologically complex site with deep water table. Proposed design includes groundwater and product recovery, air sparging to increase product recovery rates and biosparging and bioventing (2001-2004).
4. Gasoline and Diesel Spill Site, Skagway, AK
   Task leader for design of proposed in situ treatment system for extensive gasoline and diesel spill. Site is along harbour and subject to large tidal fluctuations. Remediation design includes SVE, bioventing and sparging, operated on cyclic basis. Responsible for design of well field (38 wells), civil works including piping design, process equipment and controls and contractor oversight (2001-2003).
5. SVE/Air Sparging/Bioventing – Petro-Chemical Plant, Delta, BC
   Task leader for concept design, final design, and procurement of an in situ remediation system for an extensive benzene and toluene spill at a former petro-chemical plant. The proposed remediation system consists of soil vapour extraction system for vadose zone contamination, and air and biosparging for contamination below the water table. Responsible for SVE computer modelling (AIRFLOW/SVE), and biosparging assessment and design (1995-1996).
6. Trans Mountain Pipeline Ltd. - Bioventing, Richmond, BC
   Assisted in design and construction monitoring for bioventing system to remediate jet-fuel contamination at tank farm site. Evaluated fertilizer and irrigation requirements to optimize biodegradation. Water discharge permitting and sampling for water generated during construction dewatering.(1993).
7. Railyard Site, Revelstoke, BC
   Project director for design of product recovery program, site monitoring and assessment of monitored natural attenuation (2003 - Ongoing).

PROJECT EXPERIENCE – ENVIRONMENTAL ASSESSMENT

BC Environment-Pacific Place Site
Vancouver, BC

Participated in the contamination assessment at the former Expo '86 site (Pacific Place) conducted for BC Environment. The Pacific Place site covers 200 acres of former railway, saw mill, metal shops, coal gasification plants, and in-filled dump areas. Specific responsibilities included conducting and managing field programs, database management, and quality control/quality assurance review of environmental data (1988-1992).

Coal Gasification Sites (Murrin and Pacific Place)
Vancouver, BC

Project manager for assessment of soil, groundwater, and soil gas at Murrin site, which is the location of a former coal gasification plant. Included an assessment of LNAPL and DNAPL extent and transport through soils at the site. Assisted in quantitative human health risk assessment conducted for inhalation (soil gas) exposure. Project engineer for the investigation of soil and groundwater contamination at two former coal gasification plants at the Pacific Place site (1993-1994).

BC Assessment Authority
New Westminster, BC

Conducted an independent review of an environmental site assessment report for an industrial site in New Westminster, BC. The purpose of the review was to assess the adequacy of the ESA, evaluate remedial alternatives, and prepare a remediation cost estimate in support of an evaluation of property value for tax assessment purposes. Provided expert witness services as part of Assessment Appeal Board Hearing (1996 and 1998).

Wood-Preserving Facility
British Columbia

Project engineer for remedial investigation at major wood products manufacturing site primarily impacted with creosote and chlorophenols. Assisted in design of innovative field program including cone penetration test, UV Fluorescence testing, mini piezometers, and hydropunch water sampling. Responsible for cost control (1996).

Dry Cleaner
British Columbia

Project director for investigation at dry cleaner where staged program, consisting of soil vapour survey followed by drilling program was used to delineate perchloroethylene release. The results of this assessment indicated that contaminant migration was largely controlled by site utilities.

Resumé IAN HERS

Petroleum Distribution/Storage Sites
British Columbia

Managed or conducted field investigation programs for the evaluation of soil and groundwater contamination at over forty underground storage tank (UST), pipeline, tank farm, or refinery sites in BC (1990-1997). Five project examples are listed below:

1. Refinery Site, Port Moody, BC
   Project engineer for investigation of soil and groundwater contamination at lead laydown area, separator sludge disposal area, and several tank lots (1990-1991).

2. Pipeline Site, Burnaby, BC
   Project manager for investigation of soil and groundwater contamination resulting from pipeline leak adjacent to sensitive creek. On-going monitoring of natural in situ hydrocarbon degradation (1991-1993).

3. Oil and Scraper Pit Site, Hinton, AB
   Project manager for investigation of soil contamination at location of pipeline oil and scraper pits near Hinton, Alberta (1994).

4. UST Site, Powell River, BC
   Project engineer for phased investigation at four separate UST facilities located at mill. Consisted of soil gas survey followed by investigation of soil and groundwater contamination (1990-1991).

5. BC Transit Garage, Vancouver, BC
   Technical advisor for investigation at former BC Transit garage that included waste oil USTs, fuel USTs, and garage. Designed assessment program and wrote report (1997).

GVRD-Coquitlam Landfill Site Assessment
Coquitlam, BC

Task leader for review of existing data, preparation of sampling and analysis plans, and implementation of site characterization program undertaken as part of a human health and ecological risk assessment for the Coquitlam Landfill. Included installation of shallow and deep wells to characterize hydrogeological regime, and a soil gas survey that included use of SUMMA™ evacuated canisters (1995).

Terra Nova Municipal Landfill
Coquitlam, BC

Project engineer for installation of monitoring wells, groundwater and surface water sampling, and hydrogeological assessment of contamination at municipal ("Terra Nova") landfill (1991).

Industrial Landfill Sites
British Columbia

Managed field program, consisting of installation of monitoring wells, sampling of soil, groundwater, surface water and/or soil gas, at industrial landfill sites in Burnaby and Surrey, BC (1991-1992)

Whitepass
Whitehorse, YT

Technical advisor for statistically based design of soil sampling program for large fill site.

Worksyard Sites
Coquitlam, BC

Managed field program for assessment of soil and groundwater contamination at four municipal worksyard sites located in Coquitlam (current), Richmond (former), and North Vancouver, BC (current and former). Areas of environmental concern that were investigated include USTs, garages, solvent and pesticide storage areas, material storage areas, and landfill (1993-1997).

Resumé IAN HERS

Truck Manufacturing Site Burnaby, BC	Project manager for environmental assessment of former truck manufacturing site contaminated with solvents and petroleum hydrocarbons (1995).
City of Vancouver "Block 17" Site Vancouver, BC	Managed environmental site assessment and conducted remedial planning for former industrial (light manufacturing) and commercial property located near False Creek in Vancouver, BC (1994).
Former Pipe Coating Plant Surrey, BC	Project manager for comprehensive Phase I and II assessments of former plant where large diameter pipe was coated with coal-tar. Involved review of production process, historical use of coal-tar solvents and other chemicals, generation of wastes, and implementation of a field program to investigate soil, groundwater, and surface water quality (1997).

PROJECT EXPERIENCE – GEOTECHNICAL ENGINEERING

Imperial Oil Waste Containment Port Moody, BC	Conducted site investigation, performed slope stability analysis for waste containment facility for refinery (1990).
BC Tel Lightguide Kamloops, BC	Provided field monitoring and reporting for directional drilling program (1988).
Light Industrial/Commercial Sites British Columbia	Conducted site investigation and assisted in foundation design for several light industrial projects in Lower Mainland of BC (1988-1992).
Remedial Excavation Projects British Columbia	Completed the excavation and backfill design for remedial excavation projects in BC (1992-1996).
Greater Vancouver Regional District-Coquitlam Landfill Coquitlam, BC	Project manager for design of cap for monocells containing fly-ash at Coquitlam, BC. Involved evaluation of performance-based requirements for cap, preliminary evaluation of cost, and slope stability analysis (1997).
Federated Co-op Vanderhoof, BC	Project engineer for design of drainage works for tank farm and card-lock facility (1997).

SELECTED PUBLICATIONS

Peer Reviewed and Conference Papers

Hers, I., P. Jourabchi, M. Lahvis, P. Dahlen., E.H. Luo, P. Johnson, and U. Mayer. 2014. Evaluation of Cold Climate Seasonal Factors on Petroleum Hydrocarbon Vapor Biodegradation and Intrusion Potential. Ground Water Monitoring and Remediation, Volume 34, Issue 4, pages 60–78, Fall 2014.

Lahvis, M., I. Hers, R. Davis, J. Wright and G. DeVaull. 2013. Vapor Intrusion Screening at Petroleum UST Sites. Ground Water Monitoring and Remediation. Volume 33, Issue 2, pages 53–67, Spring.

Jourabchi, P., I. Hers, K. U. Mayer, G. DeVaull, R. Kolhatkar and B. Bauman. 2013. Numerical Modeling Study of the Influence of Methane Generation from Ethanol-Gasoline Blends on Vapor Intrusion. Battelle Symposium on Bioremediation and Sustainable Environmental Technologies. June 10-13, Jacksonville, FL.

Hers, I. and E. Hood. Sustainable Approaches for Soil Gas Mitigation Systems. Peer-reviewed paper, Air Waste Management Association Vapor Intrusion Conference, October 3 and 4, 2012, Denver, Co.

Hers., I., P. Jourabchi, M. Lahvis, P. Dahlen, H. Luo., P. Johnson, G. DeVaull and U. Mayer. 2012. Cold Climate Study of Soil Vapor Intrusion at a Residential House Above a Petroleum Hydrocarbon Plume. April. Submitted to Ground Water Monitoring and Remediation. Groundwater Monitoring & Remediation. Volume 33, Issue 2, pages 53–67, Spring 2013

Lahvis, M.A., I. Hers., R. Davis, J. Wright and G. DeVaull. 2012. Vapor Intrusion Screening Criteria for Application at Petroleum UST Sites. Ground Water Monitoring and Remediation.

Hers, I., J. Lingle, F. Dombrowski, E. Murphy, T. Rees, P. Jourabchi, K. U. Mayer, 2010. EPRI Soil Vapor Intrusion Field Research Program – Evaluation of Soil Vapor Attenuation above Residual MGP Impacts at a Site in Wisconsin. Proc. Of Air Waste Management Association (AWMA) Vapor Intrusion 2010 Conference (peer-reviewed), September 26-28.

Hers, I., Roushorne, M., Petrovic, S., Lacoste, C. and M. Richardson. 2006. Overview of the State of Science on Soil Vapour Intrusion – Input to Health Canada Guidance. Proceedings of the First Canadian Federal Contaminated Sites National Workshop, Ottawa, March 7-9.

Sanders, P. and Hers, I. 2006. Vapor Intrusion in Homes over Gasoline-Contaminated Ground Water in Stafford, New Jersey. Ground Water Monitoring and Remediation, Winter.

Hers, I., Li, L. and Hannam, S. 2004. Evaluation of soil gas sampling and analysis techniques at a former petrochemical plant site. Environmental Technology, 25: 847-860.

Hers, I., Zapf-Gilje, R., Li, L. and Atwater, J. 2004. Measurement of BTX vapour intrusion into an experimental building. Un-published Ph.D. thesis paper.

Resumé IAN HERS

Hers, I., Zapf-Gilje, R., Johnson, P.C. and Li, L. 2003. Evaluation of the Johnson and Ettinger model for prediction of indoor air quality. Ground Water Monitoring and Remediation, Summer 2003.

Hers, I., Evans, D, Zapf-Gilje, R. and Li, L. 2002. Comparison, Validation and Use of Models for Predicting Indoor Air Quality from Soil and Groundwater Contamination. Journal of Soil and Sediment Contamination, 11 (4): 491-527.

Hers, I., Zapf-Gilje, Li, L. and Atwater, J. 2001. The use of indoor air measurements to evaluate exposure and risk from subsurface VOCs. J. Air & Waste Manage. Assoc. 51: 174-185.

Hers, I., Atwater, J., Li, L. and Zapf-Gilje, R. 2000. Evaluation of vadose zone biodegradation of BTX vapours. Journal of Contaminant Hydrology, 46, 233-264.

Hers, I., Zapf-Gilje, R., Li, L. and Atwater, J. 2000. Measurement of in situ gas-phase diffusion coefficient. Environmental Technology. 21, 631-640.

Hers, I., Zapf-Gilje, R., Li, Loretta, and Atwater, J., 1999. Canadian Consortium Research Project-Evaluation of Vadose Zone BTX Biodegradation. Proc. of In situ and On-Site Bioremediation – The Fifth International Symposium, April 19-22, 1999. In. Natural Attenuation of Chlorinated Solvents, Petroleum Hydrocarbons and Other Organic Compounds, Eds. Bruce C. Alleman and Andrea Leeson, 5(1), Battelle Press.

Hers, I., Zapf-Gilje, R., Petrovic, R., Macfarlane, M., and McLenehan, R. 1997. Prediction of Risk-Based Screening Levels for Infiltration of Volatile Sub-surface Contaminants into Buildings. Environ. Tox. and Risk Assessment (6th Vol.), ASTM STP 1317, Eds: F. J. Dwyer, T. Doane, and M. L. Hinman.

Rankin, M., Hers, I., Petrovic, S., Kim M., Zapf-Gilje R. 1996, “Human Health and Ecological Risk Assessment for Coquitlam Landfill Redevelopment”, Proceedings SWANA, 12th Annual Pacific Northwest Regional Symposium, April.

Hers, I., Zapf-Gilje, R., Petrovic, S., Macfarlane, M., McLenehan, R. 1996, “Prediction of Human Health Risks resulting from Infiltration of Volatile Subsurface Contaminants into Buildings”, Proceedings 6th ASTM Symposium on Environmental Toxicology and Risk Assessment, April.

Hers, I., Zapf-Gilje, R. and Boyle, B. 1994, 1995, 1996, “Remediation of Contaminated Sites in BC”, Proceedings of Fundamentals of Environmental Law and Management, The Canadian Institute Conference, Vancouver, BC, October.

Hers, I., Hamilton, G. and Patrick, G.C. 1993, “Remedial Technologies for Groundwater”, Proceedings Seminar on Management of Underground Storage Tanks, Technical University of Nova Scotia, September 14, 1993.

Zapf-Gilje, R., Hers, I., Boyle, B. and Ord, R. 1993, “Sampling Strategies and Statistical Methods for Interpretation of Soil Contamination”, Proceedings Conference on Remediation of Contaminated Sites, Insight Information Inc., May.

Hers, I. and Zapf-Gilje, R. 1991, "The Use of Statistics for Interpretation of Soil Contamination at the Former Expo '86 Site", Preprints, 44th Canadian Geotechnical Conference, Calgary.

Conlin, B.H., Hers, I. and Robertson, D. 1990, "Characterization of Former Railway Lands at the Pacific Place Site", Proceedings, Vancouver Geotechnical Society 5th Annual Symposium, May.

Zapf-Gilje, R., Schlender, M.H., and Hers, I. 1990, "The Role of Field Methods for Detection and Characterization of Hydrocarbons-Five Illustrated Cases", Proceedings Western Canadian Hazardous Waste Management and Liability in the 1990s, The Canadian Institute, Calgary, Alberta, September.

Presentations

Conference Session Chair and Invited Speaker. Battelle International Symposium on Bioremediation and Sustainable Environmental Technologies (Reno, June 27-30, 2012). Cold Climate Vapor Intrusion Research Study – Results of Seasonal Monitoring and Modeling at North Battleford Site, Saskatchewan, Canada.

Invited Speaker. Battelle Seventh International Conference Remediation of Chlorinated Recalcitrant Compounds, Monterey, California, May 24-27, 2010. "A Review of Methods and Recent Data for Estimation of Residual NAPL Saturation".

Invited Keynote Speaker. Manitoba Environmental Industry Association 2nd Annual Remediation and Prevention Conference, Winnipeg, Manitoba, February 25, 2010. "Recent Developments for Assessment and Management of Soil Vapour Intrusion".

Invited Speaker to AEHS 16th Annual West Coast Conference, Vapor Intrusion Workshop, San Diego, March 19, 2006. Presented talk on "Status of USEPA Generic Screening Levels – Update on Empirical Attenuation Factors".

Invited Speaker to Air and Waste Management Association Speciality Conference on "Soil Vapor Intrusion – The Next Great Environmental Challenge", Philadelphia, Pennsylvania, January 25 to 27, 2006. Presented talk on "A Review of Empirical Attenuation Factors from Multiple Sites".

Invited Speaker to AEHS 14th Annual West Coast Conference, Vapor Intrusion Workshop, San Diego, March 15, 2004.

Presentation at 2nd International Conference on Remediation of Contaminated Sediments, Venice, Italy September 30 to October 3, 2003 "Modeling Studying of In Situ Cap for Creosote Contaminated Marine Sediments".

Invited Speaker to U.S. EPA Workshops on OSWER Subsurface Vapor Intrusion Guidance, San Francisco December 2002, Dallas January 2003 and Atlanta February 2003.

Resumé IAN HERS

Co-Developer and Presenter, One-day Professional Development Seminars on "Investigation and Management of Contaminated Sites" and "Contaminated Sites Case Studies and Implications of Proposed Changes to Regulations in B.C.", Sponsored by University of British Columbia, Vancouver, B.C., May 28, 2002 and February 19 and 20, 2003.

Invited Speaker to U.S. EPA National RCRA Meeting, Workshop on Soil Vapor to Indoor Air Issues, Washington, D.C., January 17, 2002.

Presentation on "Soil Vapour Screening Techniques", invited speaker at training course for B.C. Ministry of Environment, Lands and Parks, March 27, 2001.

Presentation of paper on "Validation of Johnson and Ettinger model for prediction of indoor air quality using field data from petroleum hydrocarbon and chlorinated solvent site" at 2000 Petroleum Hydrocarbon and Organic Chemicals in Ground Water conference, API/NGWA, Anaheim, California, November 16, 2000.