Empirical Analysis of Vapor Intrusion Attenuation Factors for Sub-Slab and Soil Vapor – An Updated Assessment for California Sites

Paper # VI22
Presented at the Vapor Intrusion, Remediation, and Site Closure Conference December 5 - 6, 2018 Phoenix, AZ

Robert A. Ettinger,[1] Steve Luis,[2] Nadine Weinberg,[3] Todd McAlary,[4] Gina Plantz,[5] Helen E. Dawson,[6] Jeff Sickenger[7]; [1]Geosyntec Consultants, Santa Barbara, CA [2]Ramboll, Irvine, CA [3]ERM, Boston, MA [4]Geosyntec Consultants, Toronto, ON [5]Haley & Aldrich, Oakland, CA [6]Geosyntec Consultants, Washington, DC [7]KP Public Affairs, Sacramento, CA

ABSTRACT

Vapor intrusion (VI) screening levels for sub-slab and soil vapor are often calculated using generic attenuation factors (AFs) based on findings of the 2012 USEPA empirical AF study. There are limitations and uncertainties associated with the USEPA database that are often not considered when applying the results of this study for risk-based decision making at chemical release sites. For example, the USEPA database is predominantly comprised of volatile organic compound (VOC) data collected from single-family residences with basement construction and has limited data from large commercial/industrial buildings. Furthermore, the majority of these data came from states with relatively cold climates where the stack effect due to building heating is expected to enhance the potential for VI. Also, USEPA's efforts to address the influence of VOC background sources on the empirical AF may not completely resolve the bias associated with background sources. USEPA's assessment (after using a source-strength filtering process to exclude data that may be biased by indoor background sources) included only two small sub-slab datasets and two small soil vapor datasets from sites in California where the stack effect is expected to be less significant. These factors may limit the applicability of the USEPA AFs for risk-based decision making at VI sites in temperate climates (such as California) or at sites with different building construction (e.g., single-family homes without basements or large commercial/industrial buildings).

This paper presents the results of a collaborative study to compile and analyze empirical AFs derived from data collected at VI sites located in California. The sites included in this analysis reflect a range of source and building factors (e.g., single-family homes, multi-family homes, and commercial/industrial buildings). Paired indoor air and sub-slab/soil vapor data from 31 sites were evaluated in this study. With more than 1,000 paired datasets and calculated empirical

AFs, the California database is comparable in size to the 2012 USEPA national database and much larger than the USEPA data sub-set from California sites. Consequently, the empirical AFs calculated from the California dataset are more representative of conditions in California.

The California VI database was analyzed following an approach similar to the 2012 USEPA study and included a source concentration filtering of the data to exclude sample pairs that are likely influenced by VOC background sources. The median (i.e., 50th percentile) and 95th percentile values for AFs calculated from all filtered data in this study are 0.00012 and 0.0019, respectively. These results are an order of magnitude less than those reported in the USEPA study and indicate that the default AF of 0.03 recommended for site screening in the 2015 USEPA VI guidance substantially over-predicts the potential for VI at sites located in California. The results of this analysis may be used to develop conservative screening levels for VI sites in California that are protective of human health and help focus resources to locations where the VI pathway is more likely to be complete.

INTRODUCTION

Vapor intrusion (VI) screening levels are used to identify sites that may warrant additional investigation to assess potential indoor air risks. In many regulatory programs, sub-slab and soil vapor VI screening levels are calculated using attenuation factors (AFs), defined as the ratio of indoor air and sub-slab or soil vapor concentrations. When AFs are used for screening level calculations, they are often based on findings of the 2012 USEPA empirical AF study[1], and the 2015 USEPA VI guidance[2] recommends the use of a default AF of 0.03 for screening level VI assessments. This default AF is the 95th percentile of the source-concentration filtered sub-slab to indoor air AFs in the USEPA VI database. The representativeness of the AFs presented in the 2012 USEPA study has been the subject of previous research[3,4,5]. These studies suggest that the USEPA default AFs may over-predict the potential for VI exposures by an order of magnitude or more.

Although the USEPA AFs are widely referenced by regulatory agencies, the limitations and uncertainties associated with their use for risk-based decision making at VI sites are often not fully considered. For example, the USEPA database is predominantly comprised of data collected from single-family residences with basement construction, and a large majority of these data comes from a few sites located in Colorado and New York with colder climates that are expected to enhance the potential for VI due to building heating (i.e., the stack effect). Furthermore, the database has limited data from large commercial/industrial buildings. USEPA implemented data reduction measures to address the influence of background sources on the calculation of empirical AFs; however, the approach taken may not have completely resolved this confounding factor. Finally, a very small portion of the data in USEPA's assessment are from sites in California, which further limits its applicability in this state. These factors may limit the applicability of the USEPA AFs for risk-based decision making at VI sites in temperate climates (such as California) or at sites with different building construction (e.g., single-family homes without basements or large commercial/industrial buildings).

This paper presents a collaborative study to compile and analyze empirical AFs derived from data collected at sites located in California that will be more representative of conditions at California VI sites.

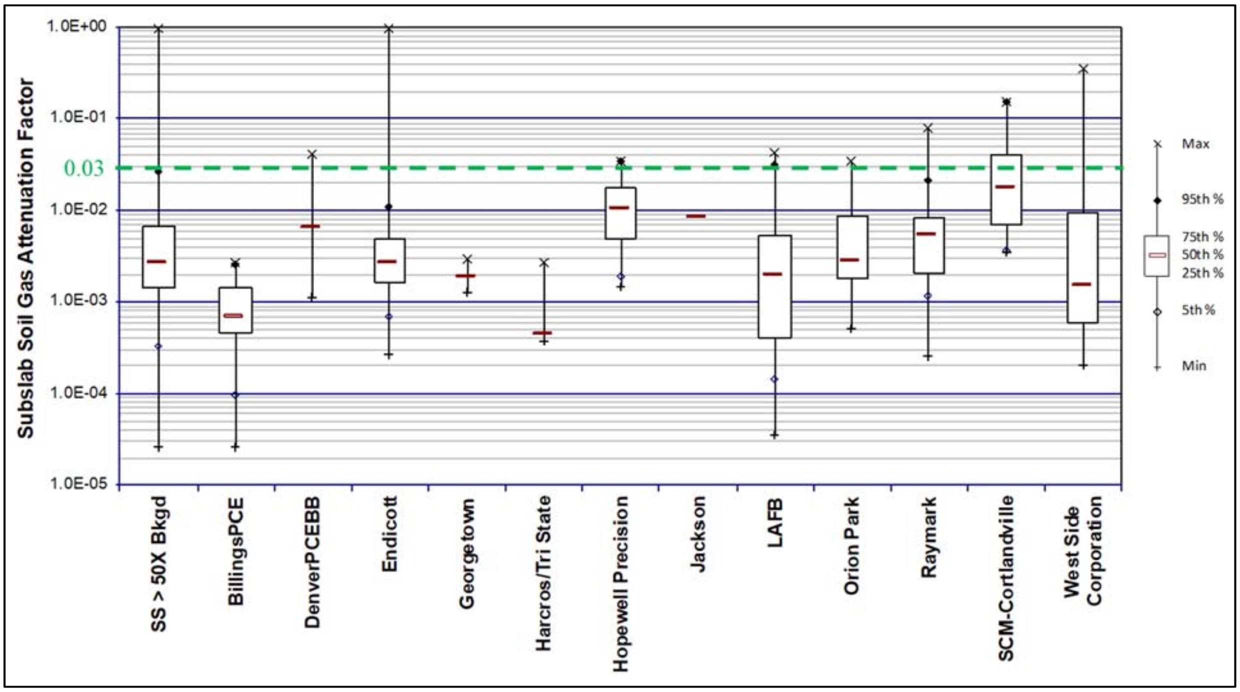
USEPA Database

The 2012 USEPA VI database contains indoor air and paired groundwater, soil vapor, sub-slab vapor, and crawlspace concentration data for VI sites across the nation that may be used to calculate empirical AFs. Overall, the database includes measurements for 41 sites in 15 states, including soil vapor data from 17 sites in 11 states and sub-slab data from 15 sites in 9 states. However, the database is largely comprised of data from a few sites with larger soil vapor and sub-slab AF data sets (greater than 10 empirical AFs). Most of the soil vapor data were collected in New York and most of the sub-slab data were collected in Colorado, Connecticut, Montana, and New York. As a result, the USEPA VI database included limited sub-slab and soil vapor data from sites located in California (all in the San Francisco Bay Area). After filtering the data for subsurface source strength, the USEPA evaluation included only two small sub-slab datasets and two small soil vapor datasets from sites in California. Building types reported in the database were 85% residential, 10% commercial, and 5 % mixed use. Furthermore, the residential buildings were predominantly buildings with basement construction, which are not representative of the vast majority of buildings in California. As a result, the USEPA VI database is not representative of conditions in California and, therefore, AFs recommended in USEPA 2015 guidance may not be appropriate for risk-based decision making at VI sites in California.

The USEPA sub-slab empirical AF results and the 95th percentile AF are shown on Figure 1. The USEPA study reported a wide range of empirical AFs for sub-slab to indoor air and soil vapor to indoor air with results spanning several orders of magnitude. The median sub-slab AF was 0.003 and the 95th percentile value was 0.03. Several sites included in the USEPA VI database did not have any empirical AFs above 0.03, which supports the conclusion that use of the generic AF recommended in the USEPA 2015 VI guidance will over-predict the potential for VI at many sites.

Sites with higher AFs were generally located in colder climates (e.g., Endicott, Hopewell Precision, and SCM Cortlandville are all located in New York) where VI is expected to be more significant due to the stack effect. This suggests that the default AFs may not be representative of conditions present in California.

Figure 1. USEPA sub-slab empirical attenuation factor results (from USEPA, 2012) and the 95th percentile value.



Effect of Background Sources on Empirical Attenuation Factors

Background sources of VOCs associated with outdoor air, indoor products, or building materials can affect the interpretation of indoor air data and resulting AF calculations[1,4,6]. When background sources are present, the measured indoor air concentrations will be comprised of VOCs due to VI, VOCs from interior background sources, and VOCs from outdoor air. Consequently, accounting for the potential influence of background sources on indoor air concentrations and the resulting empirical AF is a key consideration in the data evaluation. The USEPA performed their empirical analysis using data pairs remaining after filtering out those for which (i) background sources were identified in the field notes; (ii) indoor air concentrations were greater than the corresponding subsurface concentration; (iii) potential background bias was evident through compound ratio analysis (i.e., review of AFs for multiple chemicals from the same paired samples); and (iv) subsurface concentrations were below threshold source strength concentrations.

The relationship between the empirical AF and the contributions due to VI and background sources is shown in Equation 1.

$$AF_{emp} = \frac{C_{IA}}{C_{Sub}} = AF_{VI} + \frac{C_{Bkgd}}{C_{Sub}} \quad (1)$$

where:
AF_{emp} = empirical attenuation factor,

C_{IA} = indoor air concentration,
C_{Sub} = subsurface (sub-slab or soil vapor) concentration,
AF_{VI} = VI attenuation factor, and
C_{Bkgd} = indoor air concentration due to background sources.

Based on this relationship, the AF_{emp} will asymptotically approach AF_{VI} for large subsurface concentrations. The influence of background sources on the empirical AFs is illustrated in Figures 2 and 3. The example calculations assume $AF_{VI} = 0.003$, which is the median sub-slab AF reported in the 2012 USEPA study. Figure 2 shows the influence of background sources on empirical AFs for C_{Sub} up to 2000 $\mu g/m^3$. Figure 3 shows the same curves but focuses on the lower end of the C_{Sub} scale (0 - 250 $\mu g/m^3$) to highlight the effect of background sources at low subsurface concentrations. Background sources (C_{Bkgd}) can result in a positive bias to the calculated AF_{emp} (i.e., the AF_{emp} is greater than AF_{VI}) for cases with relatively low subsurface concentrations. For the example calculations presented in Figures 2 and 3, AF_{emp} may be more than an order of magnitude higher than AF_{VI} for cases even when C_{Sub} is in the range of approximately 100 – 200 $\mu g/m^3$.

The relative contribution of background sources to the AF_{emp} is less significant for higher C_{Sub} or lower C_{Bkgd}. To reduce the potential bias of background sources on the empirical AFs, the USEPA filtered out data pairs with clear indicators of indoor sources of background as well as data pairs with low C_{Sub}; however, the effect of background sources on the AFs likely was not completely eliminated, because the influence of outdoor (ambient air) background was not considered and the influence of indoor sources would have been difficult to discern for sample data sets consisting of only one chemical. In the USEPA study, samples with subsurface concentrations less than 50 times the 90th percentile of a literature-based background concentration were not included in the statistical analysis of empirical AFs. However, even with the approach used by USEPA to address background sources, review of the theoretical calculations presented in Figures 2 and 3 indicate that the AF_{emp} reported in the USEPA study may still be biased by background sources.

For example, the upper-end indoor C_{Bkgd} for trichloroethene (TCE) used in the USEPA study was 0.5 $\mu g/m^3$ (the green curve in Figures 2 and 3), and consequently empirical AFs with C_{Sub} less than 25 $\mu g/m^3$ were filtered from their data analysis. For tetrachloroethene (PCE), the USEPA study filtered data with C_{Sub} less than 190 $\mu g/m^3$ based on an estimate upper-end indoor C_{Bkgd} of 3.8 $\mu g/m^3$ (the blue curve in Figures 2 and 3). The background bias to the empirical attenuation factors at the source concentration filtering level for TCE (green arrow at 25 $\mu g/m^3$) and PCE (blue arrow at 190 $\mu g/m^3$) is shown on Figure 3. Using Equation 1, AF_{emp} for TCE and PCE at these C_{Sub} is 0.023. This indicates that empirical AFs at C_{Sub} slightly above the source concentration filtering level may be biased high compared to the AF_{VI} value of 0.003 by approximately an order of magnitude.

Figure 2. Influence of background sources and subsurface vapor concentration on empirical attenuation factor.

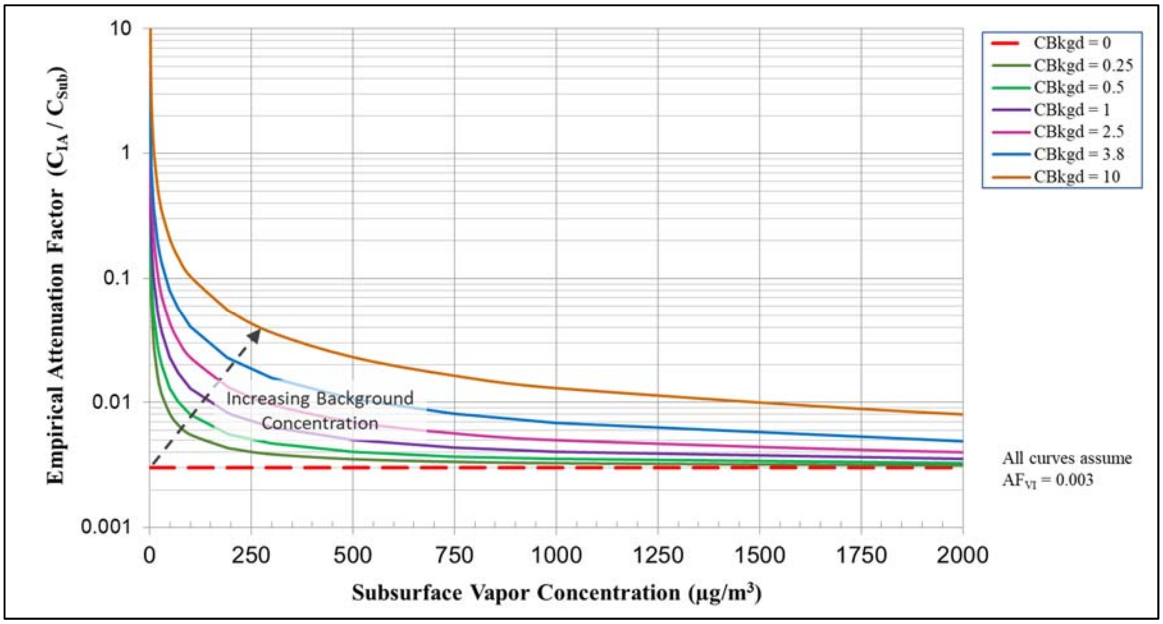
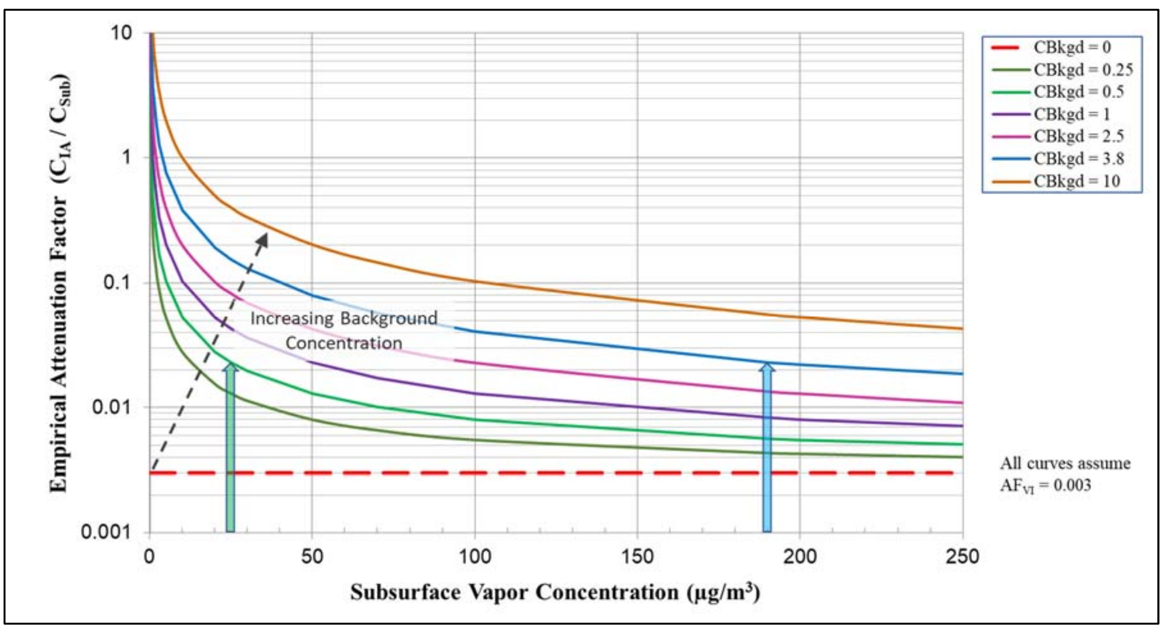


Figure 3. Influence of background sources and subsurface vapor concentration on empirical attenuation factor for buildings with lower source concentrations. USEPA (2012) source concentration filtering levels for TCE (green arrow) and PCE (blue arrow) are shown.



STUDY METHODS

For the California study, data from sites located in California were reviewed to develop a state-specific database. Sites were limited to locations where both indoor air and sub-slab or soil vapor were collected. Data from 31 sites (27 sites reviewed for this study and 4 sites from the 2012 USEPA study) were included in the California database. Table 1 summarizes the site locations, primary VI chemicals of potential concern (COPC), number of buildings, and subsurface media sampled included in the data evaluation prior to subsurface concentration filtering. As shown in Figure 4, sites were generally located in the major urban areas of the State (San Francisco Bay, Los Angeles, Orange County, San Diego), and resulted in a reasonable geographic distribution that is more representative of statewide conditions than the USEPA VI database.

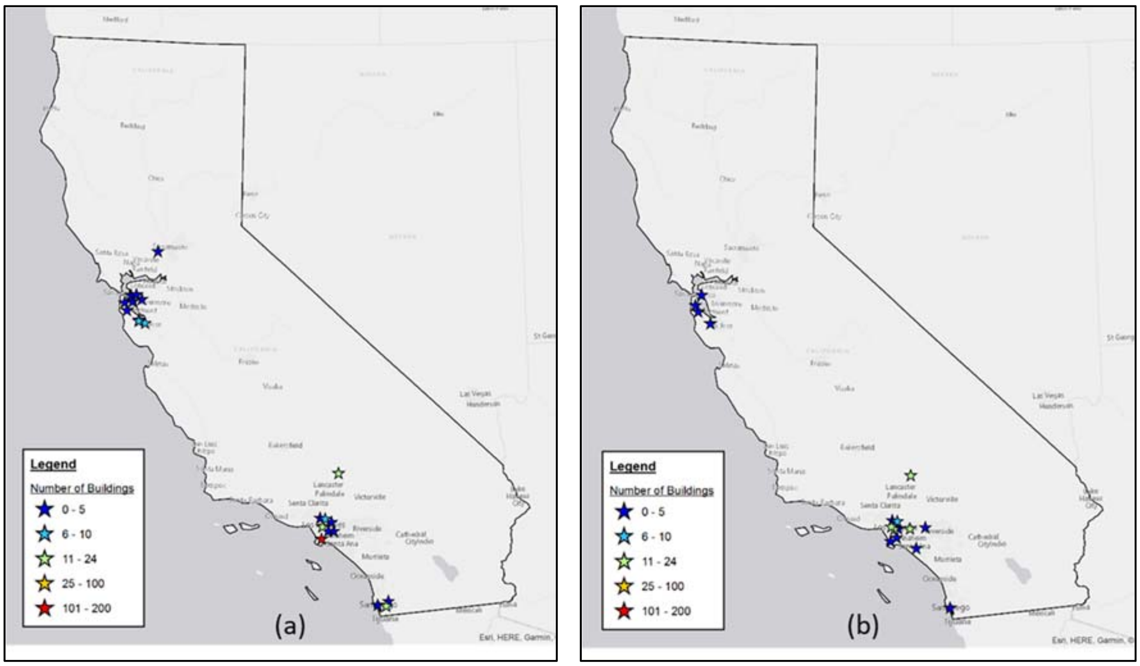
Table 1. Summary of sites included in California database

City	Land Use Description	Primary COPC	No. of Buildings	Sub-Slab Vapor Data	Soil Vapor Data
Alameda	Commercial	PCE, TCE	3	X	
Santa Clara	Commercial	PCE, TCE	6	X	
Los Angeles	Industrial	PCE, TCE	1	X	
Los Angeles	School	PCE, TCE	13	X	X
Los Angeles	Single Family Homes	PCE, TCE	17		X
Burbank	Single Family Homes	PCE, TCE	5	X	X
Los Angeles	Multi-Family Homes	PCE, TCE	9	X	X
Oakland	Commercial	CVOCs	1	X	
San Diego	Light Industrial	PCE, TCE	1	X	X
San Diego	Military	TCE	13	X	
Emeryville	Commercial	PCE	5		X
Davis	Commercial	PCE	4	X	
El Cajon	Commercial/Industrial	CVOCs	4	X	
Santa Fe Springs	Industrial	PCE, TCE, Other	2	X	
Brisbane	Industrial	PCE, TCE, Other	1	X	
San Leandro	Industrial	PCE	1	X	
SSF	Industrial	PCE, TCE	2	X	X
SSF	Industrial	TCE	1		X
Torrance	Commercial	TCE, PCE	1		X
Los Angeles	Industrial	TCE, PCE	1	X	
Orange County	Industrial	TCE, PCE	1	X	
Ontario	Industrial	TCE, PCE	1		X
Compton	Industrial	TCE, PCE	1		X
Bell Gardens	Commercial	Radon	2	X	
Carson	Single Family Homes	Petroleum, PCE, TCE	253	X	
Puente Valley	Mixed Use	PCE, TCE, Other	14	X	X
Edwards	Military	PCE, TCE	13	X	X

City	Land Use Description	Primary COPC	No. of Buildings	Sub-Slab Vapor Data	Soil Vapor Data
Alameda	Commercial	Petroleum	1	X	X
Mountain View	Residential	TCE	4	X	X
Mountain View	Residential	TCE	5		X
Mountain View	Residential	TCE, PCE	8	X	

Shaded locations were included in the 2012 USEPA VI database

Figure 4. Geographical distribution of (a) sub-slab vapor and (b) soil vapor sites included in California-specific empirical attenuation factor database



The California dataset used for this study included a distribution of building types (e.g., single-family homes, commercial/industrial buildings, slab on grade, crawl space structures, large buildings, small buildings) and source types (e.g., soil and groundwater sources).

The data were reviewed to exclude data pairs that are not reflective of VI based on the following factors:

- Site mitigation status. Indoor air data collected after the implementation of VI mitigation measures were excluded.
- Conditions inconsistent with VI conceptual site model. Indoor air concentrations greater than corresponding subsurface concentrations were excluded.
- Identified background sources. Site investigation information was reviewed to determine if a background source was identified either through the pre-sampling screening (e.g.,

VOC-containing product found) or through a multiple-lines of evidence evaluation (e.g., compound ratio analysis).

- Results below analytical detection limits. Empirical AFs were not calculated for sample pairs where either the indoor air or subsurface concentrations were below the analytical detection limits.
- Subsurface concentration filtering. As discussed above, paired data results with potential background influenced data were removed from the analysis.

The data analysis methods followed in this study were generally similar to those used in the 2012 USEPA study. Two differences in the data evaluation methods were (i) the approach used to address indoor air concentration results below analytical detection limits and (ii) subsurface concentration filtering.

A significant portion (35%) of the paired data in the California dataset consists of indoor air samples with concentrations below the analytical reporting limit or detection limit. Concentrations below the detection limit were excluded from the analysis; however, estimated concentrations (values between the reporting limit and detection limit) were included in the data evaluation if reported by the laboratory. The 2012 USEPA study statistically analyzed non-detect results using the Kaplan-Meir method and included these results in their evaluation. USEPA found that excluding the non-detect concentration data from the evaluation resulted in a high bias in the distribution of calculated empirical AFs. Consequently, the exclusion of the non-detect concentration data from the California dataset is expected to result in a high bias to the empirical AF distributions.

A subsurface concentration filtering level of 250 $\mu g/m^3$ to reduce the bias of potential background VOC sources on the AF calculations was used for all compounds in this assessment. This source concentration filtering level used for this study is slightly less than the source concentration filtering level to reduce bias associated with indoor background sources based on a theoretical evaluation[4] (300 $\mu g/m^3$). Additionally, the filtering level is approximately equal to the PCE and TCE soil vapor and sub-slab environmental screening levels (ESLs) for residential land use recommended in San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) guidance[7] (240 $\mu g/m^3$) which are based on modeled estimates for AF. As discussed above, the 2012 USEPA subsurface concentration filtering approach used a 50-fold multiplier of a literature-based indoor air background concentration for each compound. The 250 $\mu g/m^3$ subsurface concentration filtering level used for the California dataset analysis is an order of magnitude higher than the TCE filtering value (25 $\mu g/m^3$) and slightly higher than the PCE filtering value (190 $\mu g/m^3$) used in the USEPA study. Consequently, the bias due to background sources in the California-specific study is expected to be less significant than that for the USEPA study.

Summaries of the California-specific sub-slab and soil vapor datasets are provided in Tables 2 and 3, respectively. Based on these criteria, 299 empirical AFs were calculated for sub-slab data and 385 empirical AFs were calculated for soil vapor data. Note that a significant portion of the sub-slab data for residential buildings (including a large fraction of the data from the Carson site with 253 buildings sampled) were filtered from the dataset due to low subsurface concentrations for many of the paired samples. Of the 568 calculated sub-slab vapor AFs for residential properties, only 32 values remained in the dataset following the subsurface concentration filtering; therefore, the AF analysis is not skewed by the large unfiltered dataset for the Carson site. The California dataset prepared for this study is similar in size to the database created by USEPA for their nation-wide assessment (431 AFs for sub-slab and 106 AFs for soil vapor). The California dataset includes a much higher percentage of data collected at commercial/industrial buildings (47%) compared to the USEPA database (10%).

Table 2. Comparison of sub-slab vapor data in USEPA and California databases

	USEPA Database	**CA Sites in USEPA Database**	**California Database**	**Residential**	**Commercial/ Industrial**
# Sites	15	3	24	4	15
# Buildings	424	12	314	265	49
Empirical AFs	1582	15	1194	568	626
Filtered AFs	431	9	299	32	267

Table 3. Comparison of soil vapor data in USEPA and California databases

	USEPA Database	**CA Sites in USEPA Database**	**California Database**	**Residential**	**Commercial/ Industrial**
# Sites	17	3	18	5	11
# Buildings	130	5	92	67	25
Empirical AFs	235	5	986	738	248
Filtered AFs	106	3	385	329	56

RESULTS AND DISCUSSION

The ranges of empirical AFs for the California-specific dataset are shown in Figure 5 and Table 4. Distributions of AFs are shown for all data and the following sub-sets: sub-slab samples (SS), soil vapor samples (SV), residential and school buildings (Res), commercial/industrial buildings (Comm), PCE data, and TCE data. Using all filtered data (i.e., data pairs with sub-slab and soil vapor concentrations greater than 250 $\mu g/m^3$), the calculated attenuation factors range from 1.0E-07 to 9.3E-03. The median (i.e., 50th percentile value) and 95th percentile values for all data are 0.00012 and 0.0019, respectively. The 95th percentile of the California-specific dataset is similar to the values currently used by the SFBRWQCB in the calculation of the sub-slab and soil vapor ESLs for residential properties and approximately an order of magnitude lower than the default AF of 0.03 recommended in the 2015 USEPA VI guidance. Additionally, the median AF_{emp}, which is more representative of typical values, is an order of magnitude lower than the current SFBRWQCB value and two orders of magnitude lower than the USEPA default AF of 0.03.

Figure 5. Statistical distributions of California empirical attenuation factors

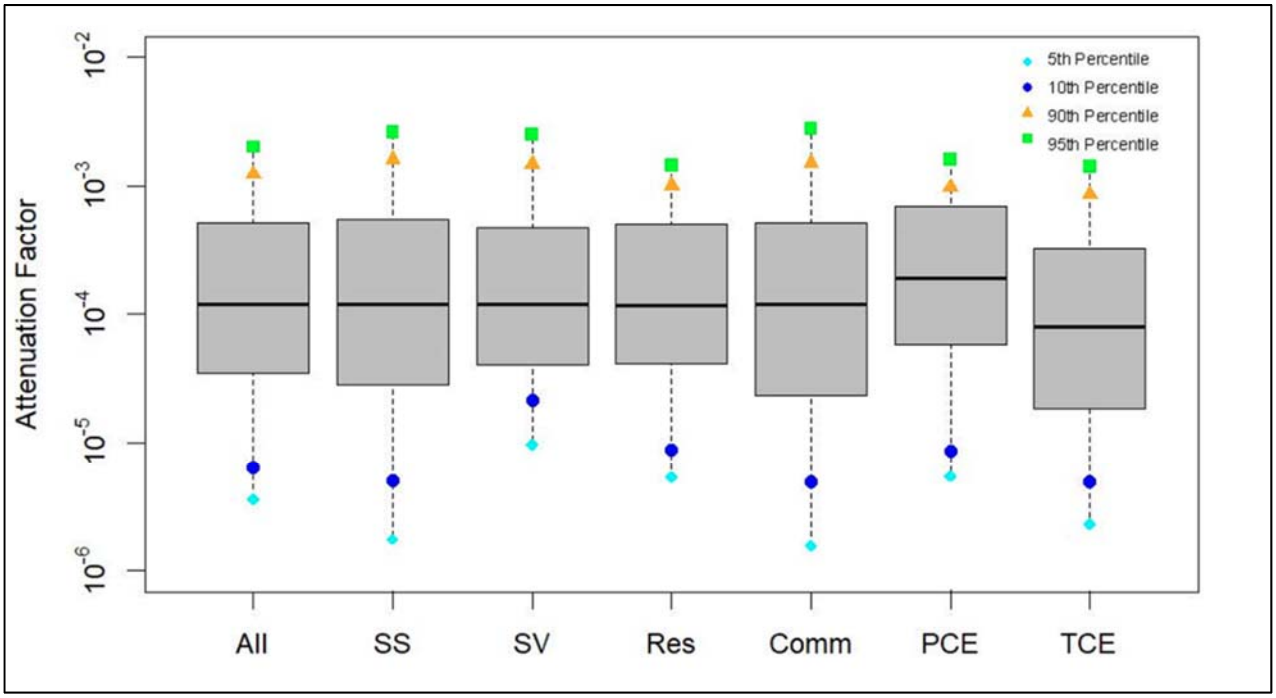


Table 4. Distributions of California empirical attenuation factors

Medium	All	Sub-Slab	Soil Vapor	All	All	All	All
Bldg. Type	All	All	All	Residential	Commercial	All	All
Analyte	All	All	All	All	All	PCE	TCE
# AFs	684	299	385	361	323	314	335
95%ile	1.9E-03	2.6E-03	1.6E-03	1.4E-03	2.5E-03	2.5E-03	1.4E-03
90%ile	1.1E-03	1.5E-03	9.6E-04	1.0E-03	1.5E-03	1.5E-03	8.5E-04
75%ile	5.0E-04	5.3E-04	4.7E-04	5.0E-04	4.8E-04	6.9E-04	3.2E-04
50%ile	1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.9E-04	8.0E-05
25%ile	3.5E-05	2.8E-05	4.0E-05	4.1E-05	2.3E-05	5.8E-05	1.8E-05

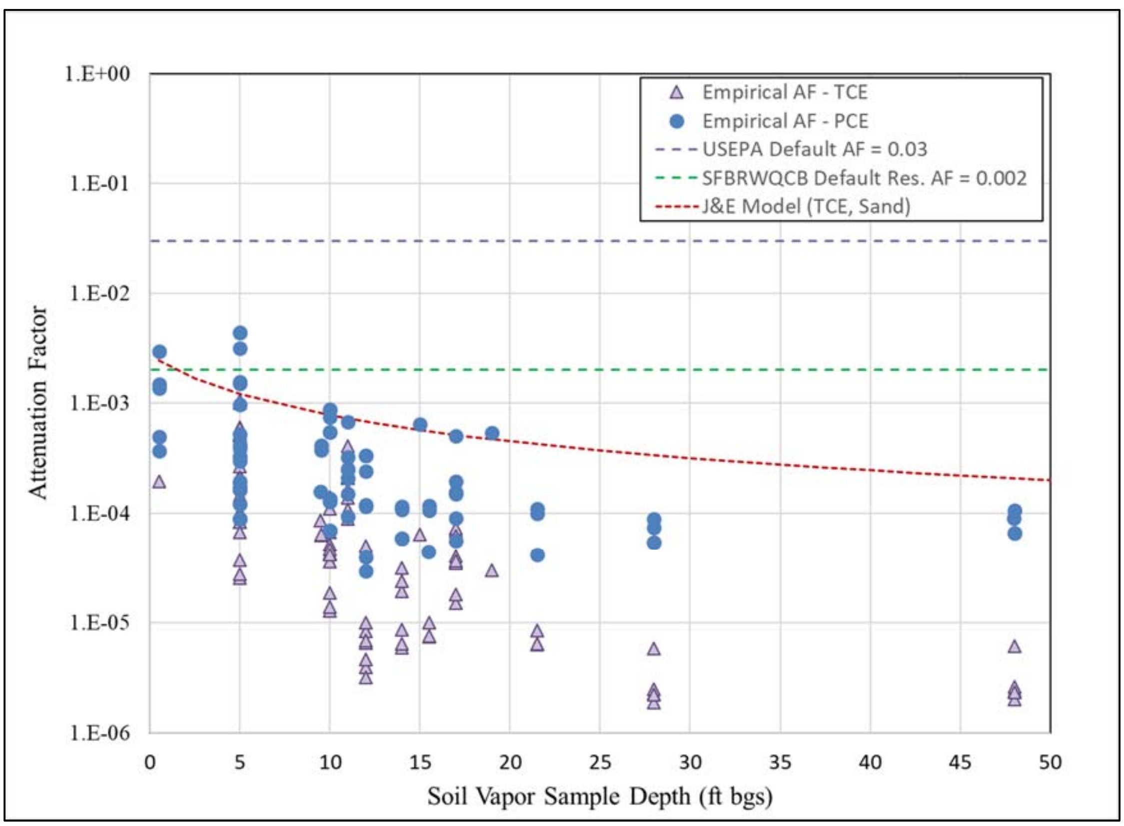
Overall, little variability is seen in the distributions of AFs for the different subsets of data reviewed (i.e., the statistical values in Table 4 are within a factor of approximately 2). More details regarding these subsets are provided below.

Sample Type and Depth Dependence

As part of the analysis, the effect of sample depth (sub-slab vs. deeper soil vapor) was evaluated. Slightly lower empirical AFs (more attenuation) were calculated for soil vapor data than for sub-slab data. However, the difference is less than what would be expected assuming the common VI conceptual model that attenuation increases (smaller AF values) with depth; however, the soil vapor dataset includes AFs calculated for a range of sample depths and a significant portion (approximately 25%) of the soil vapor AFs were calculated with subsurface samples collected at depths of approximately 5 feet below ground surface.

Potential effects of depth dependence on AF_{emp} were further reviewed through a more detailed analysis of sub-slab and soil vapor concentration data from three Los Angeles area residential chlorinated VOC sites. A decreasing trend in the maximum AF was observed as a function of sampling depth (see Figure 6). Additionally, the empirical AF data from this site were compared to USEPA and SFBRWQCB default soil vapor screening AFs for residential properties, as well as predictions calculated using the Johnson and Ettinger (J&E) model[8]. As shown on Figure 6, the USEPA and SFBRWQCB AF values over-predict the AFs observed at this site and do not capture the depth dependence of the AF (i.e., reduced AF with increasing depth). Although the figure shows a few samples collected at 5 feet below ground surface with empirical AFs slightly above the SFBRWQCB default AF, these AFs were based on detections of PCE which is expected to have higher background concentrations than TCE[9]; and as illustrated in Figure 3 background sources of PCE are expected to have a greater positive bias on empirical AFs. Finally, Figure 6 shows the J&E model results, which vary with depth. Using conservative model input values (e.g., residential property with sandy soil physical properties and air exchange rate of 0.5 per hour), the J&E model (which considers the depth-dependence) predicts results very close to the upper-bound measured empirical AFs, indicating that model results provide a useful tool for evaluating the VI pathway.

Figure 6. Empirical attenuation factors for PCE and TCE for three Los Angeles-area single-family and multi-family home sites included in the California database



The similarity between the statistical distributions of the sub-slab and deeper soil vapor AFs (Table 4 and Figure 5) is also likely influenced by the types of sites included in the California database that collected soil vapor data compared to those that collected sub-slab data. As noted in Tables 2 and 3, the filtered sub-slab dataset is predominantly comprised of commercial buildings whereas the filtered soil vapor dataset is predominantly comprised of residential buildings. The similarity in the distributions of the AFs for these different sample types is likely a function of building factors (e.g., lower ventilation rate for residential buildings that would result in higher AFs) that balance the expected smaller AFs (increased attenuation) due to the deeper sample depth. In other words, a residential building is expected to have a higher AF (less attenuation) compared to a commercial building; however, the AFs are similar due to the fact that the residential data includes mostly deeper soil vapor results and not shallow sub-slab data.

Building Type

In addition to depth dependence, an analysis was completed to assess the effect of building type on the empirical AF. Residential structures consist of buildings with smaller footprints and no or small HVAC units. Samples collected at one school site, which was predominantly comprised of portable classrooms (i.e., trailers), were included in the grouping of "residential" structures because the construction and ventilation of these buildings is more similar to residential structures than commercial structures. The "commercial" structures consist of larger buildings with commercial use (e.g., strip malls), office use, industrial use, and Department of Defense sites.

The empirical AFs in the California database indicate slightly higher values (less attenuation) for commercial/industrial buildings than for residential buildings at the 90th and 95th percentiles (Table 4 and Figure 5)). However, it is important to keep in mind that the commercial/industrial dataset is predominantly comprised of sub-slab data while the residential dataset is primarily based on soil vapor data, which were collected at depths greater than the sub-slab samples. As described above, empirical AFs calculated using soil vapor data show a decrease with depth; however, residential buildings generally have lower ventilations rates, which would result in increased AFs compared to commercial buildings. Therefore, the observed lack of a substantial difference between the residential and commercial AF distributions is believed to be due to balancing effects between sample depth and ventilation rates for the different building types.

Chemical Dependence

Empirical AFs calculated from data in the California database are predominantly comprised of samples analyzed for TCE and PCE. The data were further evaluated to assess if differences in AFs for these compounds were apparent. The distribution of empirical AFs for PCE are slightly higher than that for TCE (Figure 5 and Table 4). This trend is also evident for the dataset presented in Figure 6. Given that PCE is detected in indoor air more frequently and in greater concentrations due to background sources[9], the differences in AFs for PCE and TCE are likely due to indoor background bias described above. This suggests that the source filtering process used in this study did not completely eliminate the effect of background sources on the empirical AFs, and the results presented in this study are biased high.

CONCLUSION

A database of VI investigation results were compiled to analyze empirical AFs for sites located in California. Paired indoor air and soil vapor/sub-slab soil vapor data from more than 31 sites were evaluated making the California dataset comparable in size to the 2012 USEPA national database, and more representative of conditions for VI sites in California. Following a similar data evaluation approach to that used in the 2012 USEPA study, the results show that California-specific empirical AFs for sub-slab and soil vapor range from 1.0E-07 to 9.3E-03 with a median and 95th percentile of 0.00012 and 0.0019, respectively. These results are one to two orders of magnitude lower than the default AF of 0.03 listed in USEPA guidance and indicate that the USEPA-recommended generic AFs over-predict the potential for VI in California. The findings of this study may be used to develop conservative screening levels for VI sites in California that are protective of human health and help focus resources to locations where the VI pathway is more likely to be complete.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Matthew Lahvis from Shell Global Solutions for his thoughtful review and helpful comments to this paper.

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Key Words – vapor intrusion, attenuation factor