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Vapor intrusion risk evaluation using automated continuous chemical and physical parameter monitoring

Mark Kram[1] | Blayne Hartman[2] | Cliff Frescura[1] | Paulo Negrao[3] | Dane Egelton[4]

[1]Groundswell Technologies Inc, Goleta, California

[2]Hartman Environmental Geoscience, Solana Beach, California

[3]Clean Environment Brasil, Estr. Gov. Mario Covas, Valinhos, São Paulo, Brazil

[4]CSI Australia, Alstonville, New South Wales, Australia

Correspondence
Mark Kram, Groundswell Technologies, Inc., 7127 Hollister Ave., #25A-108, Goleta, CA 93117.
Email: mark.kram@groundswelltech.com

Abstract

Vapor intrusion risk characterization efforts are challenging due to complexities associated with background indoor air constituents, preferential subsurface migration pathways, and representativeness limitations associated with traditional randomly timed time-integrated sampling methods that do not sufficiently account for factors controlling concentration dynamics. The U.S. Environmental Protection Agency recommends basing risk related decisions on the reasonable maximum exposure (RME). However, with very few exceptions, practitioners have not been applying this criterion. The RME will most likely occur during upward advective flux conditions. As such, for RME determinations, it is important to sample when upward advective flux conditions are occurring. The most common vapor intrusion assessment efforts include randomly timed sample collection events, and therefore do not accurately yield RME estimates. More specifically, researchers have demonstrated that randomly timed sampling schemes can result in false negative determinations of potential risk corresponding to RMEs. For sites experiencing trichloroethylene (TCE) vapor intrusion, the potential for acute risks poses additional challenges, as there is a critical need for rapid response to exposure exceedances to minimize health risks and liabilities. To address these challenges, continuous monitoring platforms have been deployed to monitor indoor concentrations of key volatile constituents, atmospheric pressure, and pressure differential conditions that can result in upward toxic vapor transport and entry into overlying buildings. This article demonstrates how vapor intrusion RME-based risks can be successfully and efficiently determined using continuous monitoring of concentration and parameters indicating upward advective chemical flux. Time series analyses from multiple selected 8- and 24-hr time increments during upward advective TCE flux conditions were performed to simulate results expected from the most commonly employed sampling methods. These analyses indicate that, although most of the selected time increments overlap within the same 24-hr window, results and conclusions vary. As such, these findings demonstrate that continuous monitoring of concentration and parameters such as differential pressure and determination of a time-weighted concentration average over a selected duration when upward advective flux is occurring can allow for a realistic RME-based risk estimate.

1 | INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) describes vapor intrusion (VI) as "*the general term given to migration of hazardous vapors from any subsurface vapor source, such as contaminated soil or groundwater, through the soil and into an overlying building or structure*" (USEPA, 2015a, p. xi). Chemicals of concern that can migrate via the VI pathway include volatile organic compounds, select semi-volatile organic compounds, select inorganic compounds such as elemental mercury and hydrogen sulfide, and methane. Release and transport of these compounds through the VI pathway can result in health risks that can be estimated and compared to criteria established by regulatory agencies at local, state, regional, and national levels.

Regulatory agencies establish risk criteria used to evaluate whether long-term or short-term toxic vapor exposure risks are occurring at specific properties. Samples are collected, results are compared to established risk screening levels, and agencies determine whether additional monitoring, mitigation, or remediation is warranted and, if so, the required response timing. For instance, for trichloroethylene (TCE), EPA Region 9 and the State of California employ a residential long-term cancer risk screening level of 0.48 $\mu g/m^3$ TCE, a commercial long-term cancer risk screening level of 3.0 $\mu g/m^3$, a residential acute (short-term) noncancer risk screening level of 2.1 $\mu g/m^3$, and a commercial acute noncancer risk screening level of 8.8 $\mu g/m^3$ (California Department of Toxic Substances Control [DTSC], 2014; San Francisco Bay Regional Water Board, 2014; USEPA, 2013, 2014a, 2014b). Appropriate response actions and time frames for implementation depend upon the magnitude of the potential human health risk. For projects that exceed the previously mentioned acute risk levels, regulators may recommend accelerated response actions (e.g., mitigate within weeks). For projects that far exceed acute risks (e.g., typically three times the acute risk screening level; e.g., 6.3 $\mu g/m^3$ for residential and 26 $\mu g/m^3$ for commercial buildings), urgent responses (e.g., mitigate within days) are often required. For situations where approximately three times the urgent response levels (e.g., 20 $\mu g/m^3$ for residential and 60 $\mu g/m^3$ for commercial buildings) has been documented, building evacuations may be required. Given that concentrations can be dynamic (Holton et al., 2013; Kram, 2015; USEPA, 2015a; Hosangadi et al., 2017; Kram, Hartman, & Frescura, 2016; Kram, Hartman, & Clite, 2019; CA DTSC, 2020), sample methods, timing, and results play a significant role in the management of vapor intrusion related risks.

The most common vapor sampling methods include the use of stainless steel canisters and sorbent samplers. These samples yield a single analytical value, which is interpreted to represent a time-integrated average concentration over the duration of the sampling event. Most practitioners and regulators assume that these time-integrated results represent long-term receptor exposure conditions, often referred to as "nominal" conditions. More specifically, "nominal" conditions can be pursued by timing the sampling event to coincide with building occupancy or with ventilation systems both on and off. However, in many cases, sample timing is dictated by convenience and scheduling constraints. While these types of results are most commonly used to evaluate VI risk, individual samples may not always represent the reasonable maximum exposure (RME) concentration as defined and recommended by USEPA (2015a) because indoor concentrations are dynamic. USEPA (p.197), 2015a defines the RME as follows:

> *A semi-quantitative term, referring to the lower portion of the high end of the exposure distribution; conceptually, above the 90th percentile exposure but less than the 98th percentile exposure.*

USEPA (p.xv, p.59, p.88), 2015a further states:

> *Collect indoor air samples to characterize exposure levels in indoor air, account for seasonal variations in climate and the habits of building occupants, and ensure that related risk management decisions are based upon a consideration of a reasonable maximum vapor intrusion condition for a given building…EPA recommends basing the decision about whether to undertake response action for vapor intrusion (i.e., a component of risk management) on a consideration of a reasonable maximum exposure… EPA recommends characterizing spatial and temporal variability to increase confidence in data evaluation and decision-making and ensure consideration of a reasonable maximum vapor intrusion condition…*

Since dynamic concentration controlling factors are not typically considered, most sampling efforts are classified as randomly timed (Schuver, Lutes, Kurtz, Holton, & Truesdale, 2018). Schuver et al. (2018) further maintain that 58 randomly timed time-integrated samples would be required to achieve a 95% level of confidence in an RME estimate, which is not practical. Even so, beyond specifying seasonal events, randomly timed time-integrated samples continue to serve as the most common sampling option for evaluating vapor intrusion risks. In fact, many states even require their use (e.g., California DTSC, 2011; Massachusetts Department of Environmental Protection, 2016; New Jersey Department of Environmental Protection, 2018). Schuver et al. (2018) also argue that due to spatial and temporal concentration dynamics, conventional random timing can result in incorrect risk assessments. More specifically, they state (Schuver et al., 2018, p.7):

> *Past research on highly variable indoor air datasets demonstrates that conventional sampling schemes can result in false negative determinations of potential risk corresponding to reasonable maximum exposures (RME).*

Practitioners have demonstrated that changes in temperature, barometric pressure, ventilation, and differential pressure can impact and control dynamic indoor concentration patterns (Hosangadi et al., 2017; Schuver et al., 2018; USEPA, 2015a). Regardless of whether the controlling factor is natural (e.g., barometric pressure trend) or

anthropogenically induced (e.g., ventilation), the resulting differential pressure across the building foundation due to pressure induced advective flux often dictates whether and when vapor intrusion is occurring. Most randomly timed vapor sampling campaigns are performed without considering these important factors. This is critical because these factors can dictate the most appropriate time to sample to estimate the RME with the a high level of confidence. Therefore, if practitioners are to accept the RME-based risk criteria as correct (e.g., accept decision criteria recommended in USEPA, 2015a), since random sampling without consideration of potential controlling factors represents status quo, Schuver et al. (2018) findings imply that traditional randomly-timed samples not only fail to meet the required RME criteria, but they have an elevated probability of yielding flawed risk conclusions. This is consistent with Holton et al. (2013) when they concluded the following (Holton et al., 2013, p.13354):

> *There can be relatively high probabilities of false-negative decisions and poor characterization of long-term mean concentrations with sparse data sets typical of current practice.*

While risk assessments are often derived to estimate potential impacts associated with long-term exposures (USEPA, 1991), short-term exposures from TCE can also represent an important consideration (Forand, Lewis-Michl, & Gomez, 2012; USEPA, 2011). As stated above, many agencies consider a 24-hr exposure of 2.1 $\mu g/m^3$ as a risk to residential occupants and an 8-hr exposure of 8.8 $\mu g/m^3$ a risk to occupants in industrial settings. This is a critical point, as most randomly timed sampling campaigns require more time to sample, analyze, and process than the exposure duration of concern (e.g., 24 hr). As such, with the most common randomly timed sampling options, when the observed concentration exceeds the acute risk threshold, it is too late to prevent exposures or risks.

In addition to the issues regarding RME estimates, randomly timed time-integrated samples are also not well-suited for investigating causation (natural or anthropogenic), identifying indoor sources, or for locating vapor entry points, as temporal data patterns are not reflected in the laboratory result. Since related questions often remain after practitioners use these sampling methods, regulatory agencies typically require multiple sampling campaigns. However, engaging in multiple campaigns does not guarantee resolution, as the time-integrated sample result does not reveal data patterns sufficient to resolve these key questions. Furthermore, multiple sampling campaigns typically require months before a data set can be minimally understood.

To address several of these shortcomings, a field-stable, laboratory-grade, multiplexed analytical monitoring, and rapid response platform has been developed. The system provides concentration-triggered automated alerts to project teams who can respond to exceedances with confirmatory grab samples or immediate response actions. Integrated with a Cloud-based Internet of Things (IoT) dashboard, the system provides project teams immediate access to field analytical results and measurements which have been telemetered, mapped, and archived. Continuous concentration monitoring is often accompanied by continuous monitoring of potential controlling factors. Calculation of the time-weighted average from concentration time series analyses at appropriately selected time ranges (e.g., during upward advective flux conditions) could greatly improve the probability that the resulting RME will be more accurately calculated and, therefore, that risk assessment conclusions can be significantly improved. Added benefits include the ability to identify indoor sources, vapor entry pathways, and determine cause-and-effect correlations in a single short duration (e.g., 1–5 day) field deployment

This article describes a risk assessment approach using data derived from laboratory grade continuous concentration and controlling factor monitoring efforts. Conventional risk criteria will be employed. However, instead of using a single numerical value for the time-weighted average typically employed when randomly timed time-integrated samples are collected, the time-weighted average will be derived using an average concentration observed over several selected monitoring periods. These periods will include beginning and end times consistent with traditional 8- and 24-hr sampling campaigns employed by industry professionals that are often dictated by building access constraints or convenience. Selected times coincide with a selected window of observation where elevated concentrations and controlling factors suggest that upward advective flux is occurring.

2 | MATERIALS AND METHODS

The site evaluated is a 172,000 square foot military facility located in the coastal region of San Diego, California. This building overlies a contaminant plume comprised of volatile organic contaminants such as TCE, tetrachloroethylene (PCE), and Stoddard solvent. Six indoor monitoring points were employed in a single building. Monitoring locations were selected based on previous observations and potential for inhalation exposures. Once the monitoring locations were selected, sample lines were deployed and connected to the analytical instrumentation, and continuous analytical processing from these locations commenced in a user-defined sequence. Account holders tracked results via Internet access in near real-time.

The analytical instrumentation employed included a modified gas chromatograph equipped with detectors selected for specific analytes and anticipated concentration ranges (described in greater detail in Kram et al., 2016). The system was multiplexed with a 16-port valve component to allow for sample collection from multiple locations in the building. A five-point calibration curve was employed at the beginning and end of the monitoring campaign and exhibited negligible drift in sensitivity (e.g., <20%). Stability over several months of unattended deployment at a Superfund site has been well-documented for the same electron capture detector used for this project (Kram et al. 2019). Vapor samples were drawn from each sample location, analyzed, and the values were automatically delivered to a remote processing Cloud based IoT software platform, where the information was processed and made available within several minutes of reporting. As part of the field campaign,

barometric pressure, pressure differential, and temperature were also simultaneously monitored.

Pressure differential measurements were collected from a location near the women's restroom using a digital micromanometer (DG-700) from The Energy Conservatory (Minneapolis, MN). One port was connected to a tube extending to approximately one inch below the base of the slab while the other port was open to air inside the building. Data were recorded every 15 s and were manually retrieved on a periodic basis. The system had a resolution of 0.2 Pascal. Barometric pressure readings were automatically downloaded from a National Oceanic Atmospheric Administration web portal tracking meteorological information at the nearby airport.

For this effort, a time series analysis from a selected location was evaluated over specific temporal durations to derive multiple time-weighted average estimates practitioners would expect when employing a time-integrated sampler (such as a canister or sorbent sampler) over the same commonly used temporal durations. For instance, 24-hr continuous monitoring data should exhibit a time-weighted average result similar to a sample collected with a time-integrated sampler from the same location over the same 24-hr period (USEPA, 2015b).

3 | RESULTS AND DISCUSSION

The main objective at the facility was to employ continuous monitoring of vapor concentrations and related surface and subsurface physical parameters to understand exposure risks over space and time, and to evaluate potential mechanisms controlling risk dynamics which could then be used to design a long-term risk reduction strategy. For the risk evaluation analysis, which is the topic of this paper, the women's restroom data were selected because this location represented an area of concern from an acute TCE risk perspective, and because the highest observed concentrations were recorded at this monitoring point. Concentrations reached 417 $\mu g/m^3$ at 1:21 p.m. PST on February 6, 2016. Over the duration of the continuous monitoring program, concentrations tended to rise most during the mid-late morning, with another modest rise in the middle of the night, often through the early morning. This repetitive pattern raised questions about what might be causing the concentration dynamics.

Figure 1 displays TCE concentration versus barometric pressure over time for a monitoring location in the women's restroom. Barometric pressure readings were obtained from instrumentation deployed at the local airport. The pattern reveals a repetitive inverse temporal correlation between barometric pressure trend and TCE concentration. For instance, at the beginning of a documented drop in barometric pressure, a rise in indoor TCE concentration can be observed. Conversely, at the beginning of a rise in barometric pressure, indoor TCE concentrations decrease and remain relatively low until the next drop in barometric pressure. Note that the absolute barometric pressure value is not the controlling factor; it is the change in barometric pressure that is important. This correlation between concentration and barometric pressure trend was consistent throughout the monitoring duration.

Figure 2 displays TCE versus pressure differential for the same monitoring location. The pressure differential reflects the measured difference in pressure between a location in the subsurface just beneath the building slab and a location just above this indoors. A positive pressure differential reflects a higher pressure in the subsurface relative to indoors, whereas a negative pressure differential reflects a higher pressure indoors. For this example, pressure differential is temporally correlated with TCE concentration. More specifically, highest concentration values correspond to positive peaks in measured pressure differential. Similar temporal correlations were observed for the other monitoring locations in the building.

As with the barometric pressure trend, the correlation between concentration and differential pressure was consistent throughout the monitoring campaign. These correlations suggest that diurnal fluctuations in barometric pressure can induce differential pressure and VI (as described in Hosangadi et al., 2017). More specifically, as barometric pressure drops, the shallow subsurface may not immediately equilibrate with the pressure above the ground surface, thereby inducing a positive differential pressure, resulting in upward advective contaminant flux. This interpretation is consistent with mechanisms associated with the common coastal breeze. For instance, the heat capacity of the ocean is higher than the heat capacity of the land. As such, as incident sun rays intensify in the late morning in many coastal regions throughout the world, the air above the land heats, expands, rises, and results in a drop in atmospheric pressure relative to the pressure above the adjacent water body. A mid-day

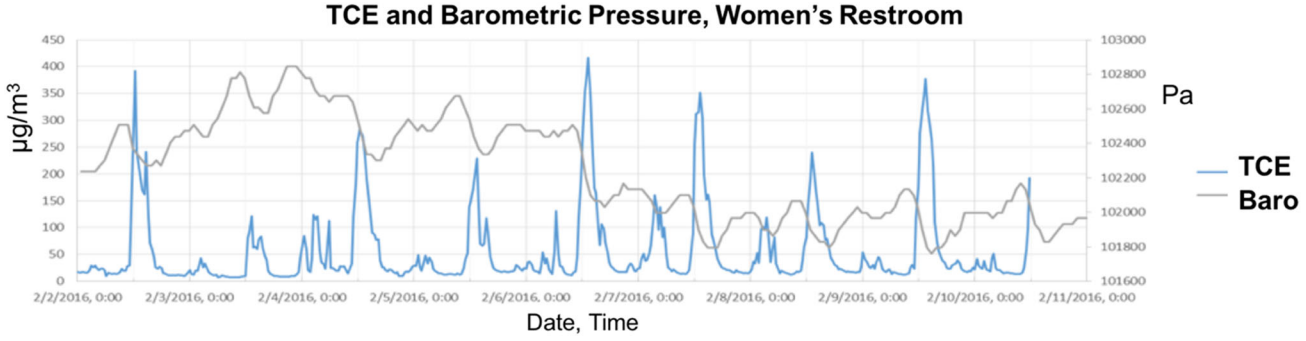

FIGURE 1 Indoor TCE concentration versus barometric pressure over time. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

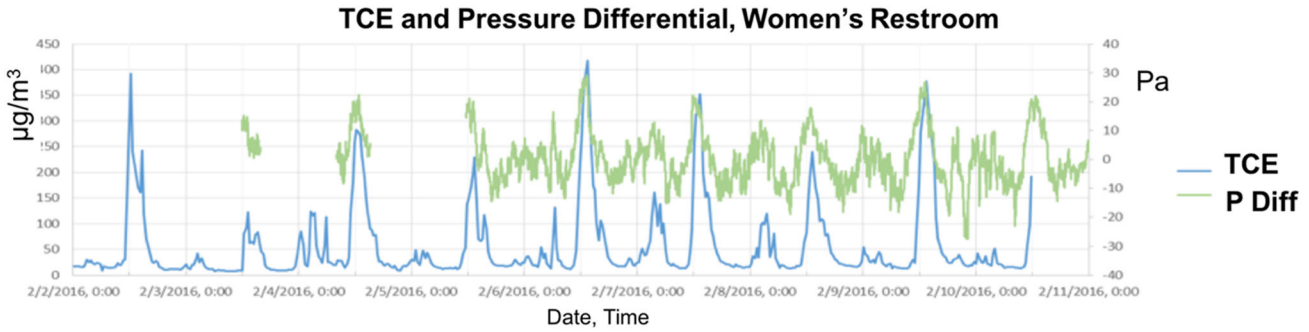

FIGURE 2 Indoor TCE concentration versus pressure differential over time. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

onshore breeze results due to the pressure differential between the air above the water body and air above the adjacent land. Similarly, when the pressure over the land drops in the late morning in the San Diego coastal region, due to the equilibrium lag, a pressure differential between the shallow subsurface and land surface is established, resulting in upward advective vapor flux. When shallow soil pores contain volatile constituents, these chemicals can also be transported upwards. During a rising barometric pressure, a reversal of the differential pressure sign (and associated vapor flux direction) occurs. As such, at least for this situation, if the RME is to serve as the decision criteria, it becomes important to sample while the barometric pressure is dropping and the differential pressure results in upward advective flux.

Additional time series charts were generated to simulate sample timing commonly employed by practitioners for 8-hr and 24-hr time-integrated sampling campaigns. Durations were selected to overlap simulated sampling times with the date exhibiting the highest concentration observed (February 6th). This was possible for all but one of the simulated time ranges (e.g., 5 p.m. to 1 a.m.). However, this time range was also included because it is very common to collect samples after workers have completed their day shift.

Figure 3 displays TCE concentration over the 9-day monitoring campaign. The time-weighted average concentration observed over this monitoring duration is 54.2 µg/m^3 and ranges from 7.3 to 417.0 µg/m^3. Figure 4 displays TCE concentration over a selected 24-hr duration spanning from 12 p.m. to 12 p.m. (to simulate a 24-hr sample beginning and ending mid-day), with a resulting time-weighted average of 80.9 µg/m^3. Figure 5 displays concentration over a selected 24-hr duration spanning from 12 a.m. to 12 a.m. (to simulate a 24 hr sample beginning and ending at midnight), with a resulting time-weighted average of 74.2 µg/m^3. Figure 6 displays concentration over a selected 24-hr duration spanning from 5 p.m. to 5 p.m. (to simulate a 24-hr sample beginning and ending just after a daytime work shift), with a resulting time-weighted average of 72.3 µg/m^3. As can be seen, while these 24-hr time periods overlap, the resulting time-weighted averages vary from each other and from the average over the complete monitoring campaign.

Figure 7 displays concentration over a selected 8-hr duration spanning from 8 a.m. to 4 p.m. (to simulate an 8-hr sample collected during a daytime work shift), with a resulting time-weighted average of 150.2 µg/m^3. Figure 8 displays concentration over a selected 8-hr duration spanning from 12 p.m. to 8 p.m. (to simulate an 8-hr sample

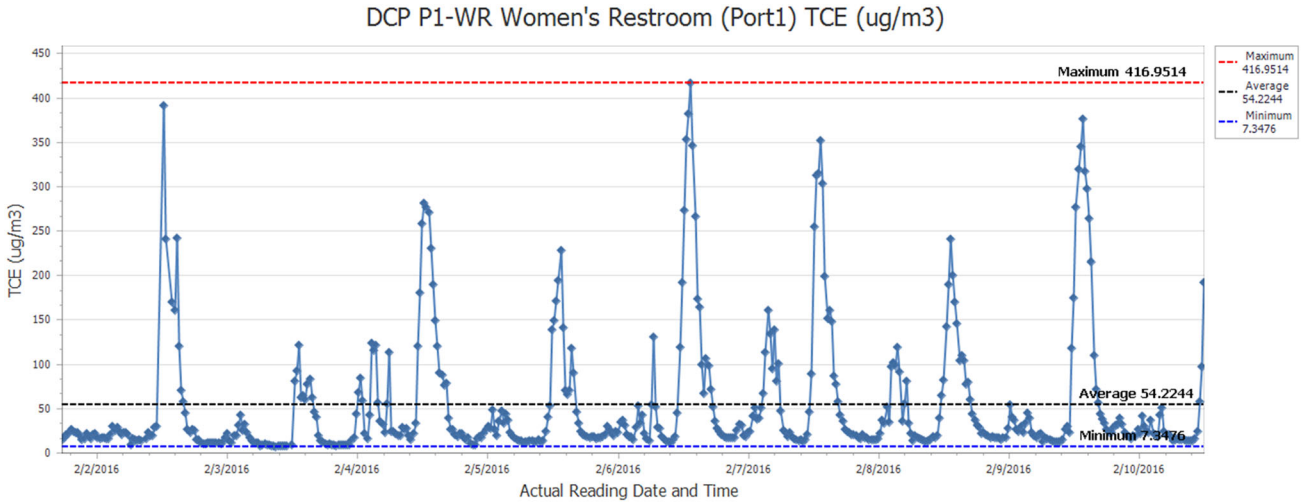

FIGURE 3 Indoor TCE concentration over time. 54.2 µg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

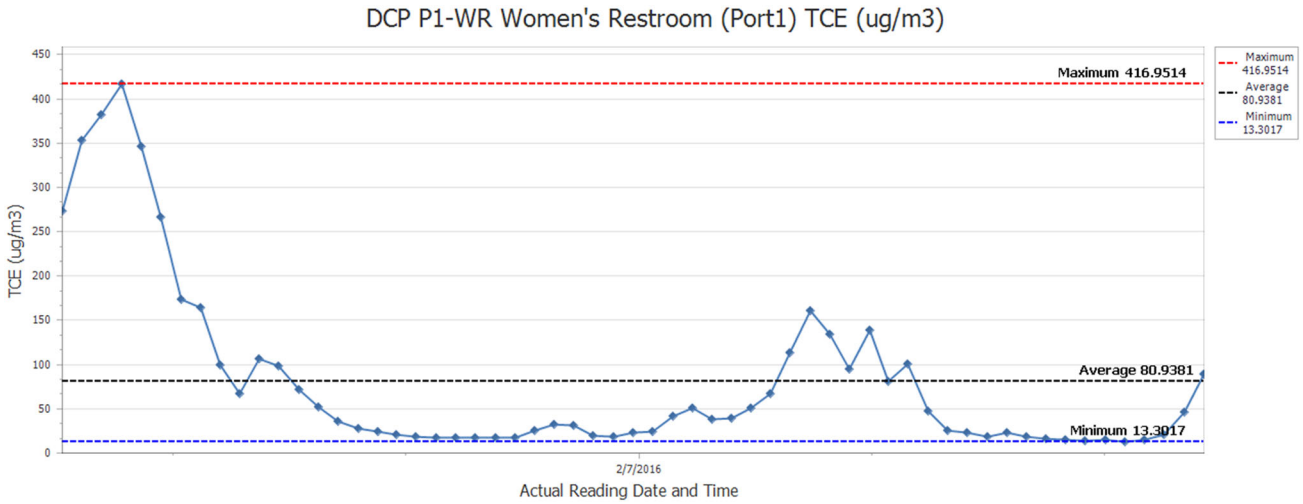

FIGURE 4 Indoor TCE concentration over 24 hr, 12 p.m. to 12 p.m. 80.9 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

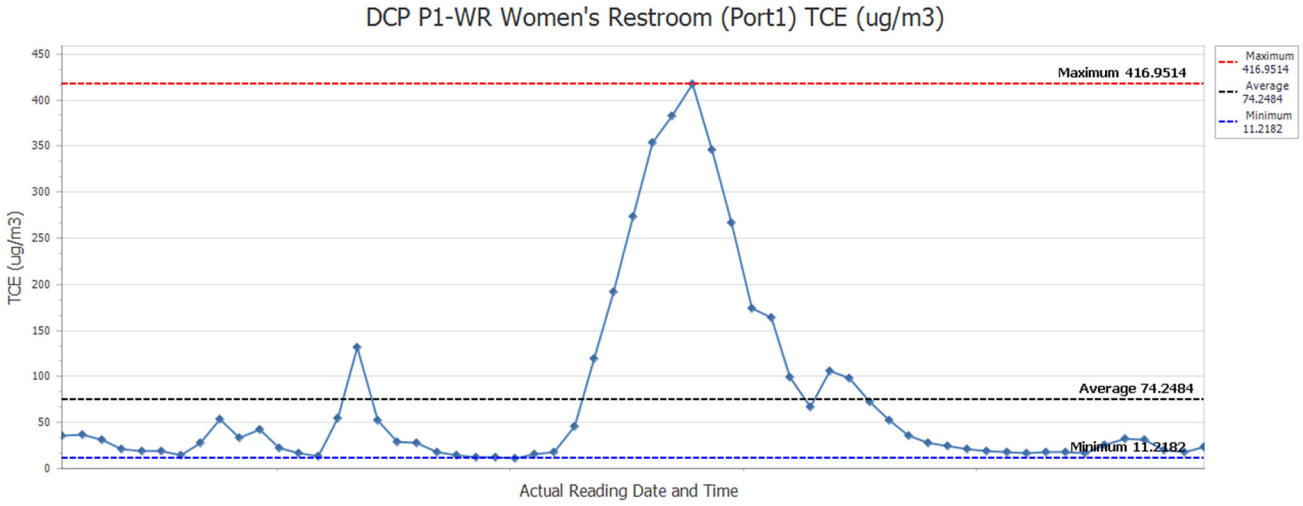

FIGURE 5 Indoor TCE concentration over 24 hr, 12 a.m. to 12 a.m. 74.2 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

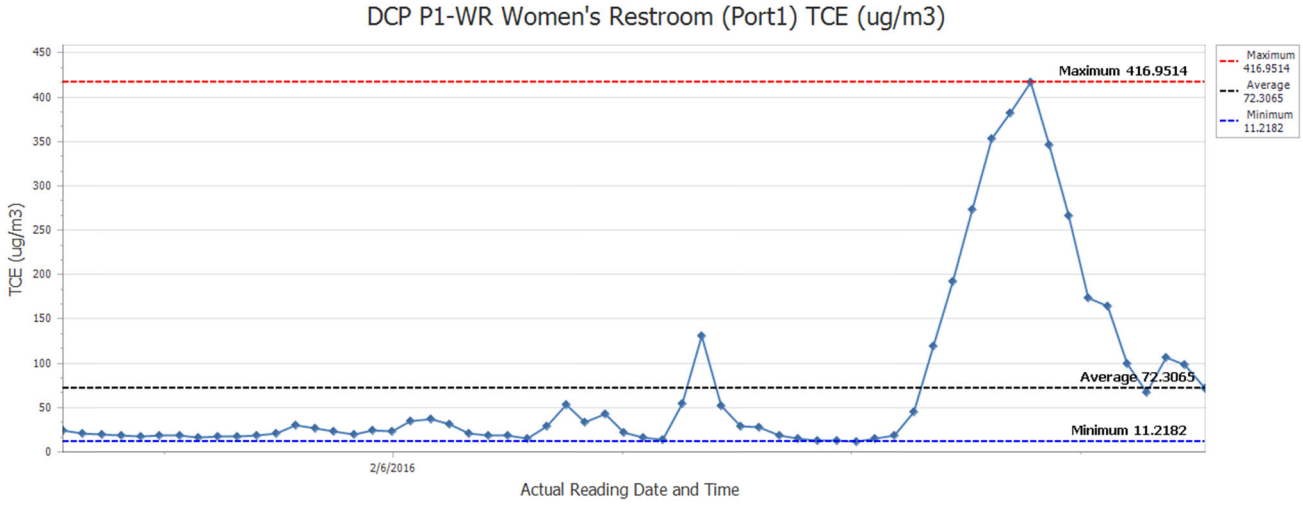

FIGURE 6 Indoor TCE concentration over 24 hr, 5 p.m. to 5 p.m. 72.3 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

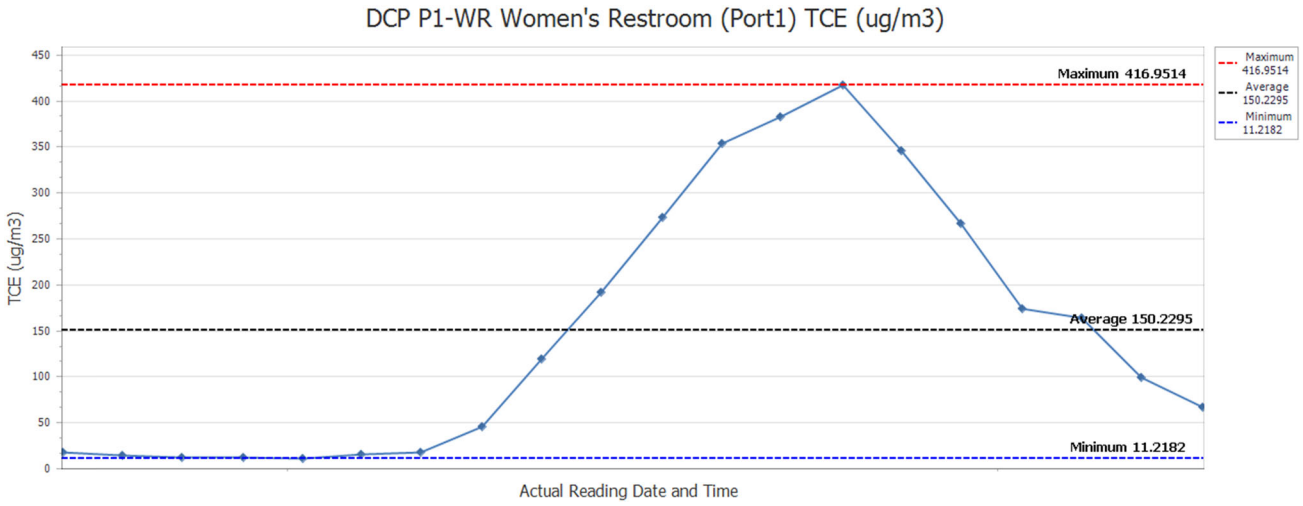

FIGURE 7 Indoor TCE concentration over 8 hr, 8 a.m. to 4 p.m. 150.2 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

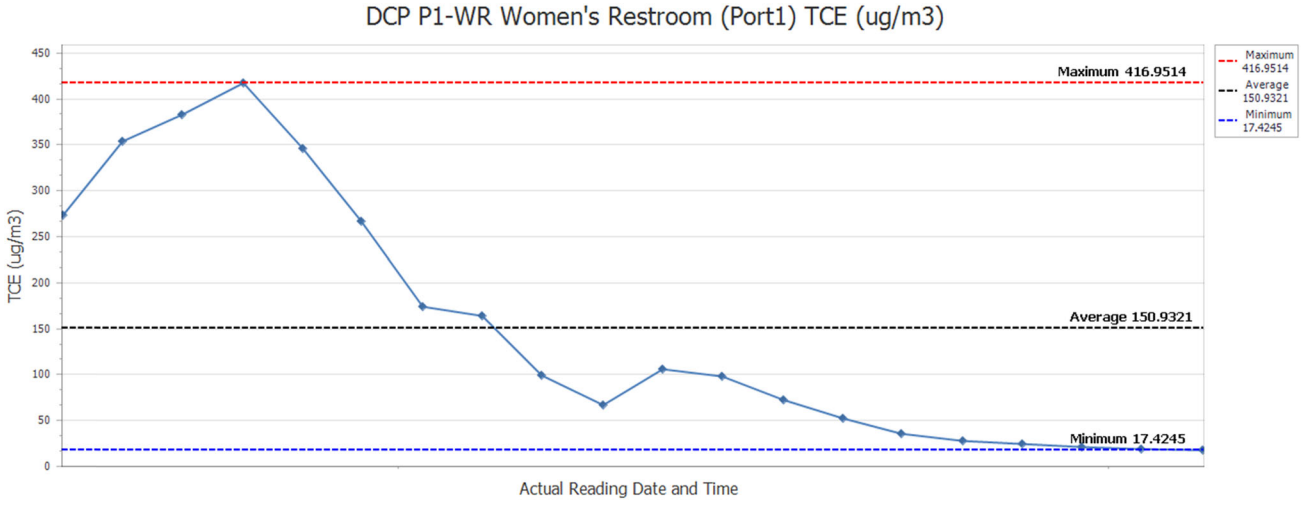

FIGURE 8 Indoor TCE concentration over 8 hr, 12 p.m. to 8 p.m. 150.9 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

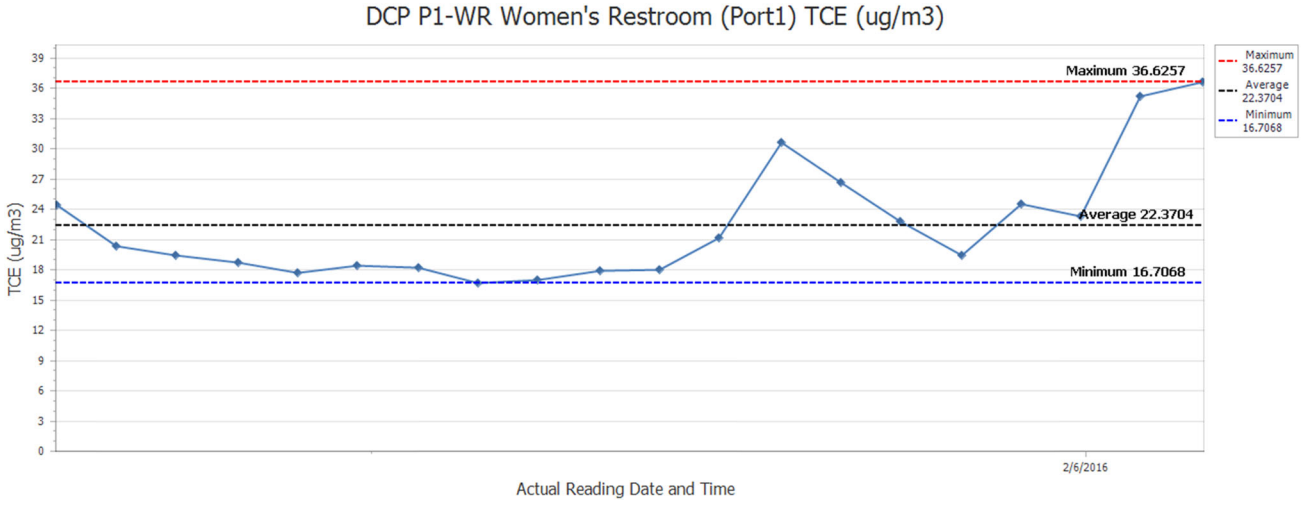

FIGURE 9 Indoor TCE concentration over 8 hr, 5 p.m. to 1 a.m. 22.4 μg/m^3 average. TCE, trichloroethylene [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Time-weighted average results for selected monitoring windows

Duration	Time range	Time-weighted average (μg/m^3)	Range (μg/m^3)	Figure
9 Days	2/2/16–2/10/16	54.2	7.3–417.0	Figure 3
24 Hr	12–12 p.m.	80.9	13.3–417.0	Figure 4
24 Hr	12–12 a.m.	74.2	11.2–417.0	Figure 5
24 Hr	5–5 p.m.	72.3	11.2–417.0	Figure 6
8 Hr	8 a.m.-4 p.m.	150.2	11.2–417.0	Figure 7
8 Hr	12–8 p.m.	150.9	17.4–417.0	Figure 8
8 Hr	5 p.m.–1 am	22.4	16.7–36.6	Figure 9

collected during the second half of a daytime work shift), with a resulting time-weighted average of 150.9 μg/m^3. Figure 9 displays concentration over a selected 8-hr duration spanning from 5 p.m. to 1 a.m. (to simulate an 8-hr sample collected after work hours), with a resulting time-weighted average of 22.4 μg/m^3. As with the 24-hr time periods, while these 8-hr time periods overlap (or at least occurred within the same 24-hr time range), the resulting time-weighted averages vary considerably from each other and from the average over the complete monitoring campaign. Also, the maximum positive differential pressure for the 8-hr duration spanning from 5 p.m. to 1 a.m. was about half that for the other selected time durations (e.g., 14 vs. 32 Pa).

Upon initial review of the results, several observations become apparent. For instance, the data patterns reflect dynamic concentrations in response to controlling factors such as barometric pressure trend and differential pressure (Figures 1 and 2). Upward advective TCE flux occurs during a drop in barometric pressure and a positive differential pressure. With the exception of the 5 p.m. to 1 a.m. sampling window, all other plots include the maximum observed concentration (Table 1). The time-weighted average concentrations, which would be the expected time-integrated sample results collected over the same duration, range from 22.4 to 150.9 μg/m^3 (a factor of approximately 7) with a standard deviation of 47.9 μg/m^3. For the 9-day window of investigation, concentrations range from 7.3 to 417.0 μg/m^3 (a factor of approximately 57). The windows of 8-hr and 24-hr investigations range from 11.2 to 417.0 μg/m^3 (a factor of approximately 37).

Given that the commonly applied short-term commercial TCE accelerated response action level is 8.8 μg/m^3 (recommend mitigation within weeks), the urgent response action level is 26 μg/m^3 (recommend mitigate within days), and the imminent hazard response action level is 60 μg/m^3 (recommend remove occupants), depending upon the sampling window, time-integrated samples collected over the various timeframes selected would yield different results and conclusions. For instance, an 8-hr time-integrated sample collected from 5 p.m. to 1 a.m. would result in an accelerated response recommendation (mitigate within weeks), while all other 8 and 24-hr samples would result in an imminent hazard response recommendation (remove occupants). This example demonstrates that sample duration and timing is critical for deriving the most protective result, conclusions, and recommendations. This also demonstrates how a few days of continuous monitoring along with derivation of time-weighted average values over the proper selected duration (e.g., during upward advective flux) allows practitioners to derive a conservative risk evaluation.

In addition to deriving a conservative risk assessment by focusing on time-weighted averages during upward advective flux conditions, the data patterns afforded by this type of analysis can allow practitioners to determine the specific duration and cause of each risk exceedance. These factors can be used for more precise long-term risk calculations and mitigation criteria. For instance, when time-weighted average concentrations are used to derive long-term risk, a constant value over the collection period is commonly assumed to occur. But if the actual exposures only occurred 50% of the collection period, it could be argued that the allowable exposure concentration can be twice the applicable risk-based concentration over the long-term. Furthermore, depending upon the timing of the exceedance (e.g., day vs. night, when ventilation is operating, under specific seasonal or climatic conditions, etc.), the risk assessment can become far more representative because factors such as occupancy timing relative to timing of the controlling factors can be tailored to meet more realistic conditions and hours of exposure per day, week, or year. The data patterns can also enable rapid risk reduction when the cause of the exceedance is determined. For instance, Kram et al. (2019) describe how the data pattern helped investigators identify a potential preferential pathway, and that by covering this, the consultants were able to reduce the concentrations to safe levels.

4 | CONCLUSIONS

Continuous TCE vapor concentrations from a selected women's restroom location were evaluated over specific time periods to derive time-weighted average estimates practitioners would encounter when employing time-integrated samplers over the same temporal durations. The objective was to evaluate selected sampling increments during times that advective flux was occurring to increase the probability of estimating the RME. The conclusions reached from this evaluation are

- Time-weighted average concentration derivations for the selected time durations ranged from 22.4 to 150.9 μg/m^3 and were highly dependent upon the sample duration and time of day. More specifically, these average values were dependent upon whether the sampling window coincided with upward advective flux conditions.

- Randomly timed time-integrated sampling approaches would have yielded different reported concentrations and, in turn, conclusions regarding risk to occupants, response and urgency of response, which again would have depended upon when the sample was collected and the time period the sample was collected over.
- Continuous high frequency monitoring of indoor chemical concentration along with factors potentially controlling vapor intrusion enables a representative risk assessment approach. This approach can produce results more closely representative of EPA's RME-based decision criteria (USEPA, 2015a) than commonly employed randomly-timed time-integrated vapor sampling approaches.
- Correlations between controlling factors and indoor concentration may not always exist. However, when correlations between continuous monitoring of chemical concentrations and controlling factors can be documented, this information can be used to determine the optimum time and time period to collect future samples at that site.

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AUTHOR BIOGRAPHIES

Mark L. Kram, Ph.D., is the founder and CTO for Groundswell Technologies, Inc., a group specializing in automated Cloud-based monitoring and modeling of environmental sensor and analytical instrumentation networks. Dr. Kram received his Ph.D. in environmental science and management from the University of California at Santa Barbara, an MS degree in geology from San Diego State University, and his BS degree in chemistry from the

University of California at Santa Barbara. Dr. Kram is the recipient of the National Ground Water Association's prestigious Technology Award, and received the 2014 ASTM Committee D18 Technical Editors Award.

Blayne Hartman, Ph.D., received his Ph.D. in Geochemistry from the University of Southern California in 1983 and has over 30 years of soil gas experience and 20 years of vapor intrusion experience. Hartman is a nationally recognized expert on soil vapor sampling, soil vapor analysis, and vapor intrusion.

Cliff Frescura is currently the Chief Operating Officer for Groundswell Technologies, Inc. He earned his MBA from the Indiana University of Pennsylvania and a B.S. in Computer Science from the University of Pittsburgh.

Paulo Negrão is the CEO of Clean Environment Brasil and has a Ph.D. in Geosciences from State University of Campinas. He also serves as an instructor at the Princeton Groundwater courses, as well as an instructor in postgraduation programs in Brasil.

Dane Egleton is the Principal of CSI Australia and is a Senior Environmental Scientist. CSI is a mobile laboratory and environmental consultancy business in northern NSW Australia. Dane has 15 years' experience in contaminated land investigations and has run multiple training courses for vapor intrusion sampling and analysis in Australia and New Zealand.

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