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white paper

In-Field Analysis Provides Insights into the Sanitary Sewer Vapor Intrusion Pathway

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Recent studies have begun pointing to sanitary sewers as a previously under-identified pathways of potential volatile organic compound (VOC) migration from the subsurface into buildings. As sanitary systems connect approximately 4 out of 5 houses in the United States, understanding this source and the vapor intrusion pathway is a matter of critical importance in public health.

Chlorinated volatile organic compounds (cVOCs), such as trichloroethylene (TCE), pose significant cancer and non-cancer risks to sensitive populations at low levels, with a Permissible Exposure Limit of 25ppm in California (CCR, Title 8, Table AC 1). Due to the serious health risks associated cVOC exposures even at low concentrations, measuring and assessing exposure has long been a priority. However, it has become clear that non-traditional, preferential pathways may create areas of risk that are removed from contamination sources. At a growing number of residential and industrial areas, elevated concentrations of chlorinated volatile organic compounds (cVOCs) have been detected at sites which do not top contaminated soil or groundwater and are without evidence of trans-

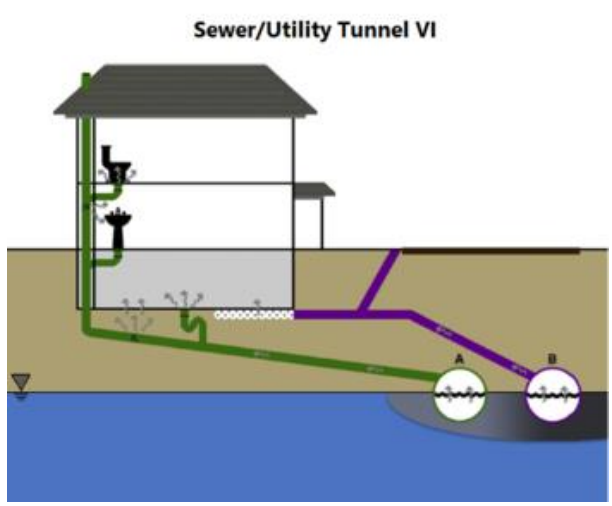

Figure 1. The Sanitary Sewer Preferential Pathway [McHugh et al. 2017]

This paper will detail the impact of in-field analysis tools, including Entanglement Technologies' AROMA technology platform, in understanding the mechanisms and extent of sanitary sewer contamination. These tools facilitate low-cost, large-area mapping of sanitary sewer systems, extended temporal analysis of sanitary sewer headspace concentrations, and rapid structure screening to identify specific points of vapor entry.

Identifying the Pathway

Municipal sanitary or combined sewer systems connect the majority of properties within urban and suburban locations where septic systems are excluded in the United States [2]. Historically, the sanitary sewer system has been thought to be fully vapor-sealed from the occupied building envelope by a system of traps, vents, and seals. This system is designed and maintained to prevent nuisance sewer odors from entering the occupied building envelope. For this reason, researchers have long assumed that vapor transport from the sanitary sewer to within the occupied building envelope would be minimal, and that any associated health risks would be negligible.

The recent identification of the sanitary sewer pathway as a primary source of indoor air cVOC concentrations has forced a reevaluation of these assumptions. Multiple current studies have demonstrated high exchange rates between sewer headspace and building envelope air [7]. These studies have shown that attenuation factors from the sanitary sewer mains to indoor air with a 10^{th} - 90^{th} percentile median of 0.013 [8], with one industrial facility in California even showing an attenuation factor as high as 0.3.

This strong exchange is driven by several key factors. First, sanitary plumbing infrastructure is infrequently maintained following building construction, if at all. Faulty toilet wax seals have been identified as points of ingress [3] as have poor connections of vent stacks in-wall. Next, even perfectly tight sewer systems may become problematic if the water level in traps falls too low due to lack of use or improper trap installation. Infrequently used floor drains are a common point of ingress in this latter category.

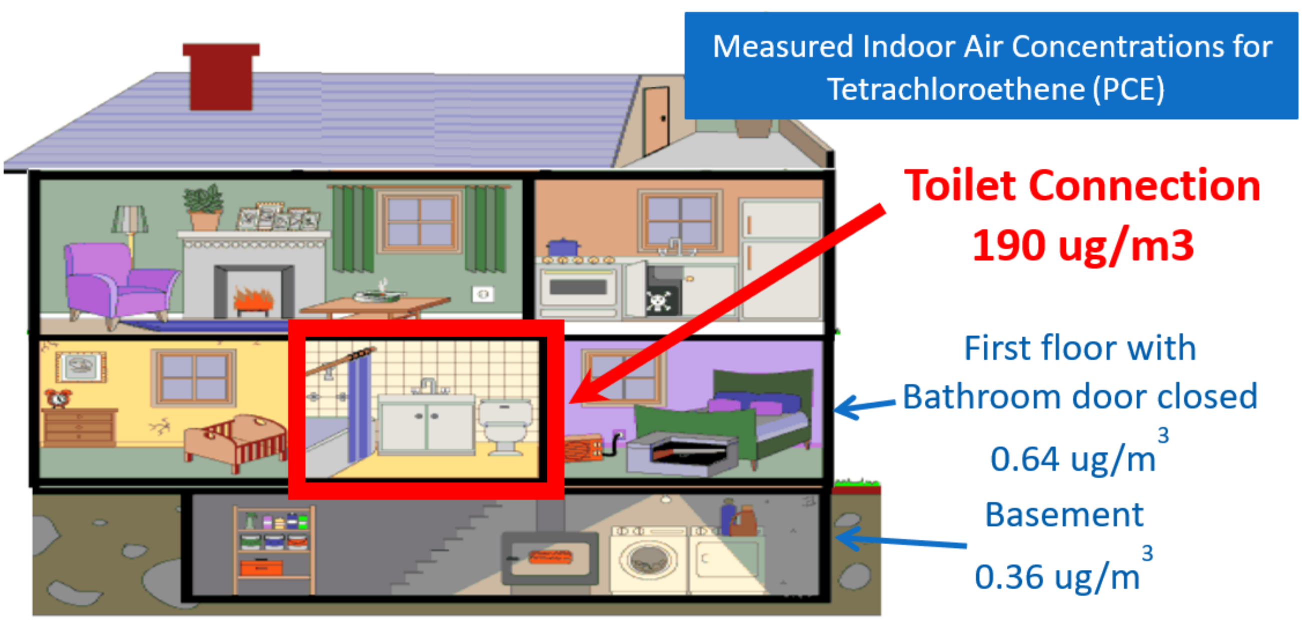

Figure 2. Sewer Gas Analysis by the University of Kentucky [3]. Reproduced with permission.

Concentrations of cVOCs in a sanitary sewer may be driven by several factors as well. A primary factor is the potential of historical chlorinated solvent discharges into sanitary sewers. As many chlorinated solvents are dense non-aqueous phase liquids (DNAPLs), discharges may lead to long-lived pools or sludges of chlorinated solvents at “bellies” within the sanitary sewer system. Defects in the sewer (common in systems older than 30 years) have led to the formation of contaminated regions where chlorinated solvents leaked from the sewer into the adjacent ground. This forms a reservoir which may re-enter the sewer system and nearby facilities. Finally, shallow, contaminated groundwater plumes may infiltrate sewer systems directly, converting a subsurface plume into a contaminated sewer system as shown in Figure 3.

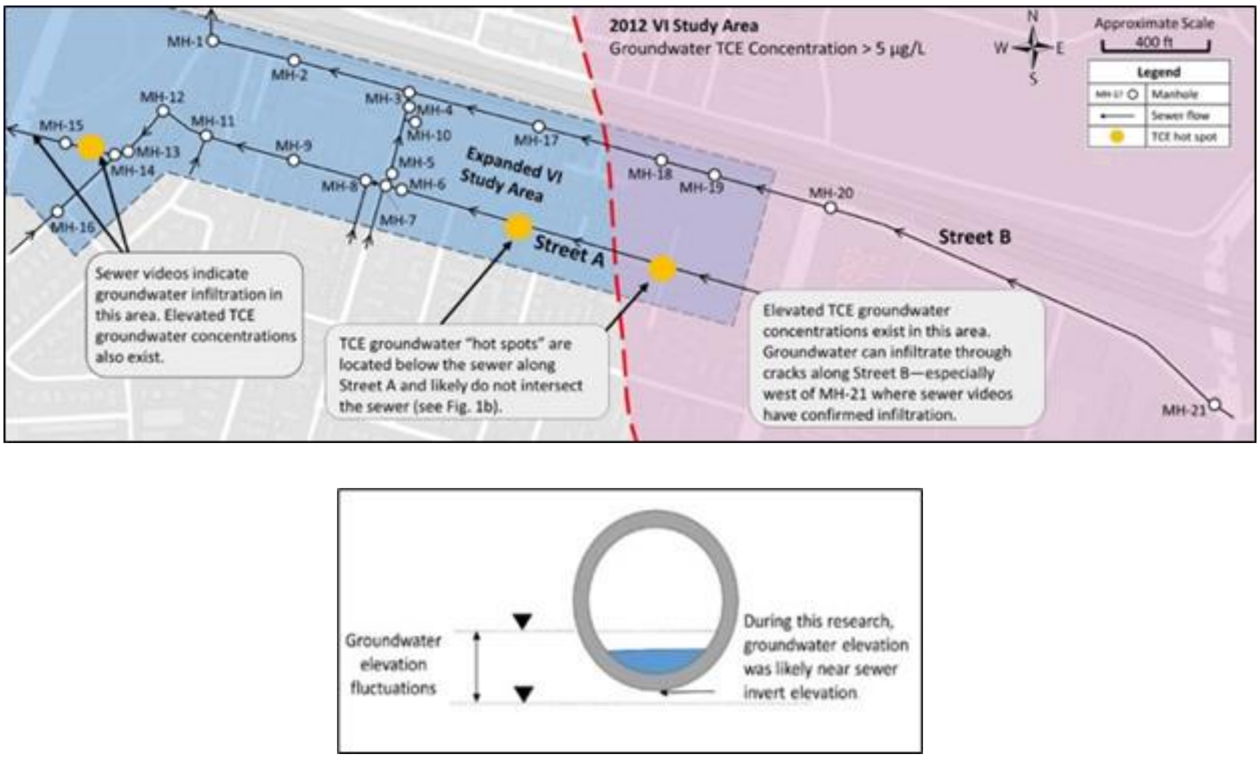

Figure 3. Sewer Gas Pipe – Plume Intersection Analysis [4]
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New technologies are proving critical to the characterization of specific preferential pathways, including through sanitary sewers, as the means of contaminated vapor ingress. They are enabling the rapid assessment of both temporal and spatial variability in the field, with results in minutes. The addition of highly sensitive, in-field analytical approaches allows researchers and technicians to quickly collect large amounts of data and track trends that would be extremely difficult to monitor through traditional approaches. These methods also reduce sources of uncertainty and project delays related to the traditional decoupling of sample collection and analysis.

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A Case Study in San Francisco

In collaboration with Dr. Kelly Pennell at the University of Kentucky and Dr. Tom McHugh at GSI Environmental, Entanglement Technologies has demonstrated sampling through man-hole vents. Using AROMA-VOC, a trace chemical analyzer, the researchers were able to identify parts per trillion levels of cVOCs such as TCE in the field in minutes. This ability to effectively capture headspace concentrations, with minimal effects on ambient air exchange with the sewer system, is imperative in facilitating high-quality, rapid assessment of sewer lines without major disruptions on traffic patterns (a significant concern in assessing regions with high population densities).

The San Francisco Bay area contains a significant number of contaminated sites due to the region's rich history of semiconductor manufacturing and high-tech industrial activity. In addition, much of the region contains shallow groundwater and sewer systems dating back over 60 years to the 1950s or 1960s. To understand the prevalence of contamination, the research team selected six sites from the California Water Board's GeoTracker database with significant groundwater concentrations of TCE for investigation. Using an AROMA-VOC instrument equipped with a sniffer-style sampling input, significant concentrations of chlorinated solvents were detected in sewer headspace at five of the six sites. Furthermore, four of these sites showed concentrations greater than 100 μg/m^3, about five times higher than concentrations associated with an excess cancer risk of 1 in 100,000 by the World Health Organization (WHO) [8] (Figure 4).

Figure 4. Bay Area Sewer Pathway Analysis

At another superfund site in the Bay area with known sanitary sewer concentrations, the research team performed a large area survey of building envelopes to assist in the identification of ingress pathways for contamination. In this case, AROMA-VOC was able to quickly identify empty floor drains in kitchens and bathrooms as the primary points of ingress, with these preferential pathways accounting for the totality of the indoor air concentrations.

The team and rapid analysis tools were further deployed to assist the University of Kentucky and the US EPA Region 9 in completing a study of the sewer pathway at an additional contaminated site within the Bay area. At this site, multiple sampling methodologies were deployed to compare techniques, including SUMMA grab samples, Radiello samples, effluent analysis, and analysis via AROMA-VOC. All sample collection approaches showed tight correlations and excellent repeatability. The rapid sampling and data output of the AROMA-VOC made it feasible to collect a large number of samples at multiple sites and to track correlations between multiple sampling locations.

This flexibility in project design and ability to capture large datasets is especially vital in analyzing the sewer pathway, which was found to be prone to extreme spatial and temporal variability in headspace concentrations. Over the course of a year-long study, AROMA-VOC tracked sewer headspace TCE concentrations at six manholes down-flow of a major contaminated site in the San Francisco Bay area. Within this region, concentrations in the sanitary sewer headspace frequently varied by factors greater than 100, with one site in particular showing concentrations ranging from 3 μg/m3 to 900 μg/m3 (Figure 5).

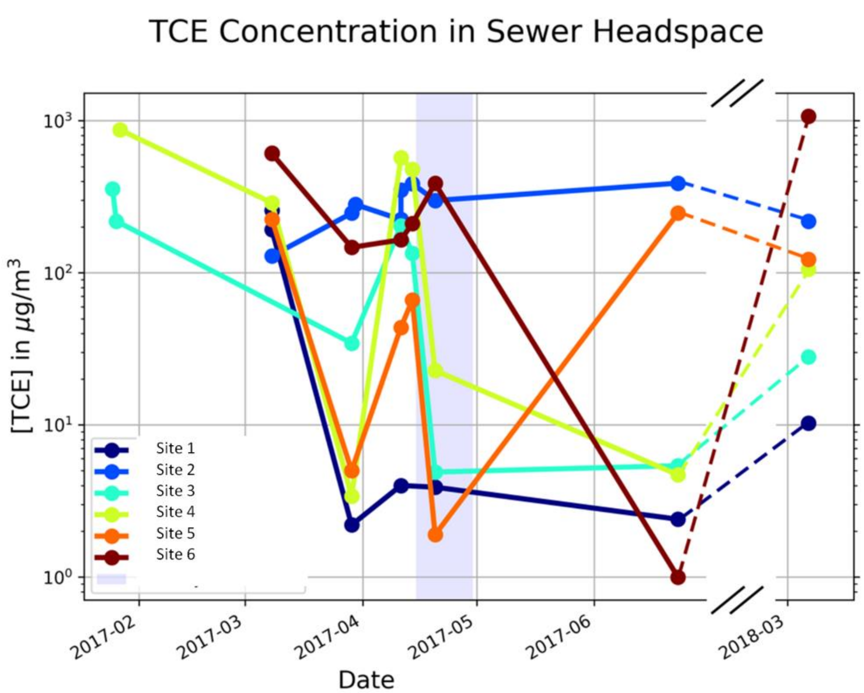

Figure 5. Sewer Pathway Temporal and Spatial Variability [our work]

These data show several important features. First, the headspace concentration was found to be extremely variable with fluctuations frequently occurring in very short timescales. This variability was further validated by sample data at a separate contaminated site where concentrations were observed to vary by a factor of 150x in only 20 minutes. Second, while some portions of a sanitary sewer may be correlated, large amounts of data will be required to properly understand and characterize a sewer system, taking into account both spatial and temporal variations.

These variabilities are not difficult to properly account for and model when supported by sufficient technologies. However, these processes require suitable measurement approaches which balance mobility with high sensitivity in order to fully account for and understand the spatial and temporal variations and their effects on sewer headspace concentrations. Even within time windows as small as a few hours, large variations in both volume and temperature of effluent within a sewer system are common; for example, this is evident when observing high volumes of hot water flowing into sewer systems in residential areas in the morning as a result of residents beginning their day with a hot shower. These variations in volume and temperature, in combination with atmospheric conditions, can dramatically affect further considerations such as direction of air flow along the length of the sewer. All of these factors impact the final headspace concentrations significantly, as well as create a net effect on potential exposures in nearby structures.

Scaling up Indoor Screening

This widespread contamination of sanitary sewers poses significant potential risks to building occupants and represents a massive, additional public health risk. Current practices only call for testing of structures specifically over groundwater plumes plus an additional buffer, typically 100 feet. This is in contrast to the majority of the detections discussed in this paper which have occurred outside of plumes [4].

Evidence from several studies has shown that the risk of vapor intrusion caused by a contaminated sewer line is comparable to that of occupying a structure over a shallow groundwater plume. One of our studies connected a structure to a contaminating source via the sewer system as far as a mile from the structure itself [unpublished]. These findings imply that a large number of homes and businesses exist with significant contamination risks that are not currently being screened,

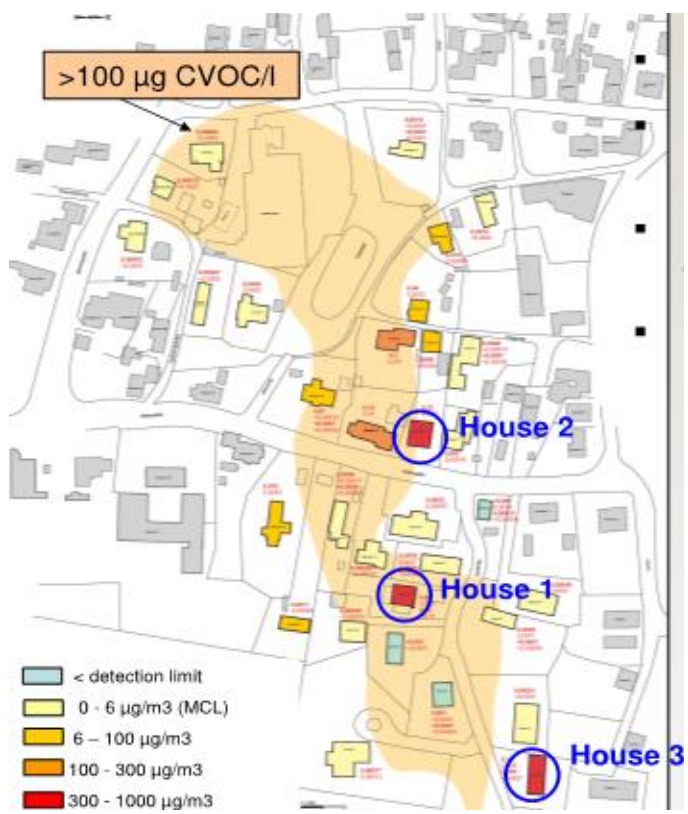

Figure 6.

potentially leaving large groups at an unidentified risk of exposure.
As this pathway becomes more known and understood, successful and rapid characterization and monitoring of potential exposures will depend heavily on rapid, highly sensitive analyzers to protect communities efficiently and cost-effectively. Proper deployment of mobile and autonomous analysis approaches and methodologies, in combination with strong public-private partnerships, will serve as the best path forward in protecting our communities and mitigating unnecessary risks.

Tony Miller is the CEO and a co-founder of Entanglement Technologies.

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