Published in final edited form as:

Prog Community Health Partnersh. 2019 ; 13(2): 141–151. doi:10.1353/cpr.2019.0028.

Public Participation in Air Sampling and Water Quality Test Kit Development to Enable Citizen Science

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Abstract

Background—Public participation in environmental data collection is a rapidly growing approach providing opportunity for hands-on public engagement in environmental field studies. This methodology is important when addressing community-identified exposure concerns.

Objectives—Our goal was to establish an academic—community partnership between University of Cincinnati (UC) researchers and local officials and residents of Guernsey County, Ohio, to address their interest in assessing environmental quality near proposed and operating natural gas extraction (NGE) waste sites.

Methods—A pilot research study was developed using community-based participatory research principles. A community resident was trained to collect air samples. Air was sampled at 10 locations for 63 volatile organic compounds (VOCs). Water quality test kits were developed in partnership with local middle and high school teachers.

Results—Community partners were involved throughout the project. VOCs were detected at all locations. Nineteen unique VOCs were detected; one was above the recommended exposure level. Findings were reported back to local officials and community members. Water quality test kits were developed and then piloted in middle school and high school classrooms.

Conclusions—Academic—community partnerships were instrumental in the identification of sampling locations, obtaining the participation of landowners, and conducting sampling. Measuring the impact of NGE activities on air quality is challenging owing to competing exposures, limited resources, and access to sites. Water quality test kits were found by Guernsey County teachers to be useful tools in the classroom.

Keywords

Air quality monitoring; community-based participatory research; community-engaged research; hydraulic fracturing; school-based; citizen science

Public participation in environmental research has experienced tremendous growth over the last decade,^{1,2} including in air quality assessment.³ This approach combined with community-based participatory research methodology offers educational and research advantages because it provides members of the public the opportunity to engage in hands-on scientific data collection.^{4–6} Combining community-based participatory research with citizen science, defined as “public engagement in scientific research with collaboration from professional scientists,” can be a very powerful tool.⁷ These combined methods are particularly useful when developing academic–community partnerships to address specific community concerns. Residents of Guernsey County, Ohio raised concerns about air and water quality owing to the rapid expansion of NGE and NGE waste injection in their county.⁸

The geologically rich resources of the Marcellus and Utica shales beneath the Appalachian region of Ohio, West Virginia, and Pennsylvania resulted in the rise of the NGE industry. NGE is also referred to as hydraulic fracturing, often in combination with horizontal drilling, and involves injection of high volumes of pressurized fluid deep into rock formations causing fractures. In addition to water, this fluid contains numerous chemicals and a proppant, typically sand, which allows the fractures to remain open so the gas can flow to the surface. It is estimated that about 3.8 million gallons of water are used at each well in the Marcellus Shale.⁹ In addition to the release of gas, NGE results in wastes in liquid (e.g., produced water or wastewater), solid (e.g., drill cuttings), and gaseous forms. Each phase of the NGE process, including wells, transportation, and compressor stations, which facilitate the transport of natural gas via 305,000 miles of pipelines,¹⁰ are potential sources of air and water contamination.^{11–16} Air emissions include greenhouse gases, VOCs, nitrogen oxides, and particulate matter.^{12,17–20} At sufficient concentrations, some of these have the potential to induce acute or chronic health effects, ranging from sensory irritation to nervous system impairment and cancer.^{21–24} Studies have found associations between NGE activity and adverse reproductive outcomes¹⁶ and negative consequences on quality of life.^{8,15} Wastewaters contain a mixture of the chemicals used to complete the well and other naturally occurring elements that are released during the fracturing process, including salts, metals, VOCs, and radioactive compounds, many with known health effects.^{25–27} Wastewaters from the Marcellus Shale have elevated levels of total dissolved solids (TDS) of up to 300,000mg/L.^{27,28} The wastewater, sometimes referred to as “brine” owing to its high concentration of salt, is managed in a variety of ways, including treatment and reuse, disposal through publicly owned or commercial wastewater treatment plants, or injection into class II underground injection control (UIC) wells. The U.S. Environmental Protection Agency (EPA) estimates that more than 2 billion gallons of these fluids are injected every day.²⁹ Reports of surface water being contaminated by wastewater from a nearby UIC well make the management of wastewater a public health concern.^{11,30} Waste facilities, often located in underserved areas, can adversely impact these communities.^{11,31}

The Appalachian Ohio region has more than 245 active UIC wells³² and increased its NGE waste disposal from 12.8 million barrels in 2011³³ to nearly 29 million barrels in 2015,³⁴ with about one-half coming from neighboring states. This dramatic increase in NGE waste, and corresponding increases in other NGE activity, has caused concern among community members of Guernsey County and neighboring counties. Guernsey County is a rural Appalachian county with a population of 39,063, a median household income of \$41,566, and 18.6% of the population is below the poverty line.³⁵ Guernsey County is also home to nine UIC wells as well as numerous producing and permitted NGE wells.³⁶ It was reported that, in 2015, 3.0 million barrels of waste were disposed of in Guernsey County.³⁷ A recent proposal for a NGE solid waste facility in a Guernsey County business park further heightened community concerns.³⁸

Herein we describe how an academic—community partnership was developed with researchers at the UC and community residents and officials from Guernsey County to assess baseline air quality near proposed and active sites of NGE activity. In addition, we collaborated with local schools to develop a citizen science water quality toolkit to provide youth with a hands-on learning opportunity that implements the scientific method to address a potential problem facing their community.

METHODS

Development of the Academic-Community Partnership

Guernsey County Commissioners signed a resolution opposing a proposed NGE solid waste site, saying, “The board of commissioners feels that we (Guernsey County) are already absorbing more than our share of frack-related waste with multiple injection wells being located in our county.”³⁸ The commissioners concern about the potential impact of the facility on environmental quality and public health led former commissioner and retired health teacher for the Rolling Hills School District (R.R.) to reach out to an environmental health scientist (E.N.H.). E.N.H. was invited to a Guernsey County commissioner meeting, where these concerns were discussed and research needs identified.³⁹ The commissioners expressed an interest in knowing air and water quality before the onset of the proposed NGE solid waste facility and at other locations in the county near active UIC wells. Thus, an academic—community partnership was formed among Guernsey County residents (R.R.) and county officials (G.B.). This partnership developed a pilot grant application for the UC Center for Environmental Genetics. The team received one-half of the budget requested and came to a consensus to focus on air quality assessment and develop a citizen science tool for water quality assessment by engagement of the local middle and high schools. All pilot project funding was used to provide compensation for the community member (R.R.), VOC analyses, and supplies for the water test kits. The UC Institutional Review Board determined the study was not human subject research.

Air Sampling Locations

Air quality assessment sites were determined in consultation with the Director of the Guernsey County Emergency Management Agency (G.B.) with assistance from the Guernsey County Maps Department. Once the intention to assess air quality was

communicated by the local media, concerned residents contacted E.N.H. and R.R. requesting that the air sampling also be conducted near two compressor stations and a NGE producing well. Thus, 10 air sampling locations were identified in Guernsey ($n = 7$), Belmont ($n = 1$), Noble ($n = 1$), and Muskingum ($n = 1$) counties (Figure 1). R.R. visited the property owners to provide a detailed explanation of the proposed study and obtain permission for the team to locate an air monitor on their property.

The coordinates (latitude and longitude) of each sampling site were recorded using a GPS device. Because 300 m has been used as an outer range for measuring air pollutants,⁴⁰ any potential sources of VOCs within a 300-m radius, including major roads, farms, gas stations, and industry, were documented visually and via Google Earth.⁴¹ The Ohio Department of Natural Resources oil and gas locator website³⁶ was also accessed to identify nearby NGE activity. Distances between air sampling locations and potential VOC sources were measured via Google Earth.⁴¹

Air Sampling and Analyses

A community member (R.R.) was trained to operate, store, and ship the air sampling devices, as well as complete Chain of Custody forms. All devices, training, and sample analyses were provided by ALS Environmental, an Ohio EPA Voluntary Action Program and American Association for Laboratory Accreditation accredited laboratory located in Cincinnati, Ohio. R.R. and each homeowner identified an open area on the property to place the monitor. The monitor was hung from a shepherd's hook to obtain air quality measurements within the breathing zone.

Air samples were collected and analyzed using an existing standardized protocol provided by ALS. Air quality was characterized by measuring VOC concentrations and formaldehyde. Ambient air was sampled for VOCs over a period of 24 hours. R.R. deployed a total of four devices at each sampling site over a 2-week period. The schedule was adjusted as necessary to avoid sampling in the rain. There were a total of 12 days where samples were collected during a 6-week period from October 2016 through November 2016. Temperature, precipitation, humidity, wind speed, and wind direction were recorded each sampling day. After the 24-hour sample period had ended, the VOC canisters and formaldehyde samplers were shipped to the laboratory (R.R.).

VOCs were determined using batch-certified clean evacuated stainless steel canisters and 24-hour flow controllers. Flow rate over the 24-hour sampling period was controlled at a constant rate of 3.5 mL/min. Analysis was performed using cryogenic pre-concentration gas chromatography with mass spectrometry per guidance contained in the US EPA Compendium Method TO-15.⁴² Analysis included 62 VOCs. Passive sampling was performed for 24-hour integrated average formaldehyde concentrations using a SKC (Eighty Four, PA) UME 100 passive sampling device. Although this is a device typically used as a personal air sampling device, it was used for stationary sampling. Analysis was performed using liquid extraction with acetonitrile and measurement of the dinitrophenylhydrazone derivative using high performance liquid chromatography with ultraviolet detection (high-performance liquid chromatography/UV), per US EPA method TO-11A.⁴³

Development and Pilot of Water Quality Test Kits

Given that NGE wastewater or brine would contain a high level of salt, a potential marker of water contamination would be elevated levels of TDS. The UC Center for Environmental Genetics Community Engagement Core (E.N.H. and R.S.) had previously developed a prototype of a water quality test kit to measure TDS and pH to enhance science, technology, engineering, and mathematics education for middle and high school students. This pilot project provided the opportunity to receive feedback on the kit from classroom teachers. Kits include devices for measuring TDS and pH, water collection cups, a water bottle, and a project guide and data collection sheet for students. The project guide provided guidance on the collection of water from streams, ponds, and tap water. R.R. invited a middle school teacher and a high school teacher from Guernsey County to pilot the water quality test kits in the classroom. The water quality test kits were incorporated into their Science and Environmental Science curriculum. Calibration solution was provided to ensure accuracy of the devices (TDS and pH). Teacher feedback resulted in a decrease in the number of water collection cups, the addition of a teacher resource guide, improvement of data entry instructions, and the expansion of the student project guide to include water quality education and a more detailed results interpretation section. When discussing the water quality test kit, one teacher who was involved in the pilot shared, “It provides an opportunity for our students that they generally would not get owing to the socioeconomic status of the region they live in. It has already played a major role in how I am instructing on some specific areas in my curriculum. Next year I am planning on expanding the number of students involved and trying to utilize the kits in more ways.”

RESULTS

Air Sampling

We developed a successful academic—community partnership that achieved the project’s objectives. Together we selected 10 air sampling locations in proximity to current or proposed sites of NGE activity, obtained cooperation from landowners, and conducted air quality monitoring over a 6-week period. Air sampling results were shared at a Guernsey County commissioners meeting to provide them the ongoing study’s progress and discuss new directions for potential research studies. The commissioners appreciated these baseline data given the potential for hydraulic fracturing activity in their county. This meeting was reported by local media.^{44,45} In addition, individual report-back letters were developed by the academic—community team (all authors) and shared with property owners at each sampling location. R.R. personally contacted each property owner to thank them for their role in the study and provide additional information, if needed.

NGE operations, including diesel-powered equipment and trucks, have been reported to release pollutants at each stage of the NGE life cycle.^{17,19} Table 1 outlines the NGE sites and other potential sources of VOCs within 300 m of the 10 air sampling locations. A producing NGE well was near one sampling site (site 10) and compressor stations 1,100 m and 1,440 m away from two sites (sites 9 and 10, respectively). Although beyond 300 m, these were recorded as residents reported strong odors and precedent existed for detection of VOCs at similar distances.¹⁹ UIC wells were near three sites (sites 1 through 3). Three

sampling locations (sites 6, 7, and 8) were in close proximity to the proposed NGE solid waste facility to gather baseline air quality measurements. Three sites (sites 4, 6, and 7) had permitted/not drilled wells within 300 m, per Ohio Department of Natural Resources website.³⁶ No current NGE activity was within 300 m of seven sites (sites 4 through 10); five of these seven had other potential nearby sources of VOCs such as motor vehicle traffic or industry.

We had 40 air samples collected from 10 sites. Each air sample was analyzed for 62 VOCs and formaldehyde, providing analyses of 2,520 VOCs. Only 120 of these VOCs (4.8%) were above the level of detection. Within these 120 VOCs, there were 19 unique VOCs detected (Table 2). The most frequently detected VOC was acetone, found in 87.5% of all samples, followed by chloromethane, found in 75% of all samples. Also provided in Table 2 are any available US EPA Reference Concentration for Inhalation Exposure values, which are an estimate of a continuous inhalation exposure concentration to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime.⁴⁶ The only sample from all sites that exceeded the Reference Concentration for Inhalation Exposure (trichloroethene, at 0.52 ppb; Reference Concentration for Inhalation Exposure of 0.40) was collected from site 5. Trichloroethene is frequently used as a solvent or degreaser. Severe short-term overexposure to trichloroethene can result in coma and long term occupational exposure has been linked with scleroderma and kidney cancer.⁴⁷

Water Quality Test Kit Pilot in the Classroom

The partnering middle and high school teachers received an Innovative Educator Award presented by the UC Community Engagement Core during their school board meeting to publicly recognize their outstanding contribution in developing these test kits.⁴⁸ The Ohio School Board Association also highlighted the success of the collaboration by making it the feature cover story for their June issue of the *Ohio School Board Association Journal*.⁴⁹ These media highlights resulted in positive recognition for the school district and county.

The final version of the water quality test kit includes TDS and pH devices, calibration solution/powder, water collection materials, a data collection sheet, a student project guide, and a teacher resource guide. The kits can be viewed on the Community Engagement Core website.⁵⁰ During the pilot, students measured water quality from the field and in the classroom. Water samples were from their home drinking water source ($n = 37$) and local streams, lakes, or ponds ($n = 30$). Google Fusion Tables⁵¹ was used to provide a platform for student mapping and sharing their data (Figure 2).

DISCUSSION

Our academic—community partnership addressed county commissioners' and community residents' concerns regarding air quality before the onset of a proposed NGE solid waste facility and at other locations in the county near active UIC wells. Although we were not able to conduct a scientific study related to water quality, we were able to build the capacity for future citizen science by developing a water quality test kit for the classroom. Each step of the air sampling was completed in partnership⁶: establishing objectives, identifying and selecting sampling locations, data collection, and the dissemination of findings.

Communication was essential throughout the project, requiring almost daily phone calls and several in-person meetings in Guernsey County.

The air sampling was unique in two major areas. First, contrary to most published NGE-related air sampling, this project was proactive in collecting baseline measurements to allow for comparison with values after initiation of NGE activities. For example, after our sampling concluded an NGE well was drilled 500 m from one sampling location (site 5) and follow-up air measurements could now potentially demonstrate any change. The community is now poised to determine air quality impacts associated with increased NGE activity. Second, the selection of sampling locations was driven primarily by local officials and residents, as evidenced by the expansion of the initial concept of baseline measurements at potential waste sites to include active UIC wells, compressor stations and a producing NGE well. The final locations were very different than had they been selected by the research team acting independently.

The air sampling offered several challenges, each with its own lesson. The greatest challenge was gathering accurate information about current NGE activities. We worked closely with the Director of the Guernsey County Emergency Management Agency, seeking to reconcile apparent differences between online resources such as the Ohio Department of Natural Resources website³⁶ as compared with Google Earth⁴¹ and visual inspection. We learned that there was not a comprehensive, accurate source of NGE facilities, a concern for emergency responders. It was also a challenge to characterize VOCs from an individual source. We learned that access to NGE sources was restricted and sampling can vary widely owing to atmospheric conditions, production level, differences in the composition of the gas, the uniqueness of each source, the level of emissions control, the VOCs sampled, the type of NGE activity sampled, and proximity to the source and nearby VOC sources such as vehicular traffic or industry.^{12,17–19,52}

It is anticipated that most rural communities with similar levels of NGE activity and other sources of VOC emissions would have similar measurements to the current study. However, given the limited scope of this study and the myriad of factors that can influence measurements, variability between communities should be expected. We recommend baseline measurements be taken at any potential NGE site and routine monitoring be conducted thereafter to characterize long-term exposures. In addition, water and soil sampling should be performed. Community members interested in understanding the impact of nearby NGE activities should collect data such as truck traffic and gallons of waste injected.

The air sampling was limited in scope and the collection of just four samples at each site does not provide conclusive findings. VOCs are ubiquitous and, although only three sites had NGE activity within 300 m, VOCs were detected at all sites. The site with the largest number of VOCs detected (site 5) was located 162 m from a highway, and three gas stations and a truck stop were at the 300-m radius.

Several point source measurement studies have demonstrated that the various stages of NGE activity emit VOCs, including compressor stations, UIC, and NGE wells.^{19,53–55} Beyond

100 m the contribution of individual point sources may not be distinguished from background levels⁵⁶ nonetheless, the source can still contribute to ambient VOC levels.¹⁶ All NGE activities in our study were beyond 100m from the sampling device; however, Ohio setback rules⁵⁷ allow for dwellings and occupied structures 150 feet from producing wells, much closer than our sampling distances.

Reports of the impact of NGE-related VOC emissions on ambient air quality have ranged widely; some have detected levels above recommended exposure limits for human health, ^{22,52,58,59} whereas others have not.^{56,60,61} These divergent findings are not surprising given the variability of measurements between sampling sites or even at the same site owing to the previously noted factors. In addition to the potential human health impact from NGE-related VOC emissions, the emissions have the potential to harm the environment.^{18,54}

Comparison with other NGE sampling in the Appalachian Basin is useful because it can potentially minimize regional differences owing to gas composition. There has been limited VOC air sampling in this part of Ohio. The Ohio EPA conducts VOC air sampling at several sites throughout the state,⁶² including Coshocton, a town approximately 30 miles from our nearest sampling site, from 2000 to 2002. Despite occurring in a town, with traffic and industry contributing to measured VOCs, the mean value for acetone in Coshocton was measured at 2.76 ppb, a value similar to our mean of 2.60 ppb (data not shown). Human activity such as motor vehicle traffic and industry typically raises the level of VOCs; acetone is commonly measured at 7 ppb in urban settings.⁶³ In 2013, the Ohio EPA began continuous VOC monitoring within one-half mile of an NGE well in one of the same counties as our sampling, Muskingum County. Measurements were reported monthly from May to October 2013 for 10 VOCs.⁶⁴ The monitoring is reported as “baseline,” but it is unclear if the measurements were taken before or during NGE activities. All reported values were below recommended exposure levels. Intermittent VOC sampling was also conducted at an unreported distance from the same well. Mean and maximum values are reported for 22 detected VOCs, with all maximum values below recommended exposure limits except for one sample of naphthalene. In a small study in three Ohio counties near our sampling sites, four grab samples and five passive samples were all below recommended exposure levels.¹⁹

NGE activities across the state line in Pennsylvania are widespread and Ohio receives NGE waste from Pennsylvania for injection into UIC wells. Although several studies in Pennsylvania reported VOC levels below recommended exposure levels,^{60,65–68} others concluded that NGE-related emissions pose a significant risk.^{18,69} Elevated levels of formaldehyde were detected in six of 10 passive samples collected up to 790 meters from a Pennsylvania compressor station.¹⁹

Piloting the water test kits in the classroom provided substantial improvement to the kit's contents. Working closely with the teachers was critical for this improvement. Numerous requests for water test kits were received as a result of the positive media attention regarding the collaboration between the school district and the university to develop science, technology, engineering, and mathematics education opportunities for school-aged children. We assembled and distributed 110 test kits to six middle schools and eight high schools in Guernsey, Muskingum, and Noble counties, the Guernsey County Soil and Water

Conservation District, and other youth educational programs. Kits will be used in a variety of courses, including science, biology, chemistry, environmental science, health education, outdoor education, geology, and vocational agriculture. Use of the water test kits in the classroom offers an innovative pedagogical method to provide practical experience in scientific inquiry, critical thinking, and problem solving a real-world problem affecting their community. The role of citizen science in the K-12 classroom has been virtually unexplored.⁷ Combining community-based participatory research with citizen science is a creative way to increase the public's engagement in science and significantly impact reach and translation of scientific results.⁷⁰

The current study has limitations. In general, sampling for VOCs at NGE sites has demonstrated significant variability within and between sites.^{12,17–19,52} Therefore, sampling ideally would have been more extensive and spanned a substantially longer time period to capture variations in season, atmospheric conditions, vehicular traffic, changes in production, and any unique events such as a spill. Also, while the VOCs detected could be related to NGE activities, the current study cannot quantify what contribution NGE activities may have had toward measured VOC values. The water test kits were piloted for use in the classroom, but further modifications would be needed to make them highly functional for citizen science outside of the classroom, in environmental organizations, for example.

This study highlights the lessons learned associated with characterizing community exposures associated with NGE activity (incomplete NGE information and difficulty in characterizing VOCs from an individual source), and the importance of working closely with community members to develop user-friendly tools for citizen science. These partnerships are particularly useful when addressing issues in underserved populations.^{71,72} Although limited in scope, this study provides a dataset of baseline VOC measurements at proposed NGE locations as well as values potentially related to NGE activity among a rural population. NGE activities are commonplace in Appalachian Ohio but are more extensive elsewhere. Therefore, the data gathered here can help with understanding any association between the quantity of NGE activities and the impact on ambient air.

ACKNOWLEDGMENTS

The authors acknowledge the valuable contributions of the local residents who participated in the air quality study, the Guernsey County commissioners for their guidance, as well as the Guernsey County Emergency Management Agency and the Guernsey County Maps Department. We also acknowledge Zane Zehnder and Hope Bradshaw, the teachers who piloted the water quality test kits with their students and whose feedback was instrumental in the success of the water quality test kits. This work was supported by funding from National Institute of Environmental Health Sciences (P30ES006096). The study was performed when authors E.N.H. and R.S. were with the University of Cincinnati.

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Figure 1.
Map of Air Sampling Locations throughout Muskingum, Guernsey, Noble, and Belmont
Counties, Numbered 1 to 10

Figure 2.
Map of Water Samples Shared via Google Fusion

Table 1.

Number of Unique Volatile Organic Compounds (VOCs) Detected at Sampling Locations and Distance From Potential VOC Sources

ID - County	Distance to Potential VOC Sources	No. of Unique VOCs Detected
1 - Muskingum	128 m from UIC well; 268 m from Interstate highway;	2
2 - Guernsey	5 commercial sites within 300 m including a gas station, auto repair shop, and steel fabricator	2
3 - Guernsey	188 m from UIC well	4
4 - Guernsey	157 m from UIC well	3
5 - Guernsey	4 permitted/not drilled NGE wells within 300 m; proposed site for UIC	15
	162 m from Interstate highway;	
	300 m from three gas stations and a truck stop	
6 - Guernsey	224 m from proposed solid waste site; 58 m from permitted/not drilled NGE well; farming during sampling	8
7 - Guernsey	80 m from proposed solid waste site; 206 m from permitted/not drilled NGE well; farming during sampling	4
8 - Guernsey	723 m from proposed solid waste site; 70 m from municipal airport runway	10
9 - Belmont	1,100 m from compressor station	5
10 - Noble	540 m from producing NGE well; 1,440 m from compressor station	9

NGE = natural gas extraction; UIC = underground injection control.

Table 2.

Summary of Detected Volatile Organic Compounds (VOCs)

Detected VOC	EPA RfC (ppb)	LOD (ppb)	% (n) of samples above LOD	Highest Value Detected (ppb)
Acetone	379.4	1.0	87.5 (35)	8.1
Benzene	9.4	0.5	2.5 (1)	1.2
2-Butanone	1697.9	0.5	22.5 (9)	2.7
Carbon disulfide	224.8	0.5	2.5 (1)	0.84
Chloromethane	43.6	0.5	75.0 (30)	1.0
Dichlorodifluoromethane	N/A	0.5	15.0 (6)	0.71
Ethyl acetate	N/A	0.5	10.0 (4)	1.5
Ethylbenzene	230.3	0.5	2.5 (1)	0.76
Formaldehyde	750.0	4.3	17.5 (7)	7.9
Heptane	N/A	0.5	2.5 (1)	0.97
Hexane	200.0	0.5	15.0 (6)	3.1
Methylene chloride	172.7	0.5	10.0 (4)	1.4
2-Propanol	N/A	1.0	15.0 (6)	11.0
Propene	N/A	0.5	5.0 (2)	3.2
Toluene	1326.7	0.5	5.0 (2)	5.1
Trichloroethene	0.4	0.2	2.5 (1)	0.52
1,2,4-Trimethylbenzene	12.2	0.5	2.5 (1)	0.69
m,p-Xylene	23.0	0.5	5.0 (4)	3.2
o-Xylene	23.0	0.5	2.5 (1)	1.0

EPA RfC = U.S. Environmental Protection Agency Reference Concentration for Inhalation Exposure; LOD = level of detection; ppb = parts per billion.