Community-Based Monitoring and Air Quality: Citizen Scientists as Data Collectors in the University Village Community and Quantifying the Effects of Nearby Industrial Practices in West Berkeley and Albany, California

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ABSTRACT

Community-based monitoring (CBM) has been used in communities around the United States to allow residents of impacted communities to conduct environmental testing and surveying. I employed CBM methods of surveying and air quality testing in University Village—an industrial fenceline community—to collect data about malodorous emissions believed to come from a nearby steel foundry. Residents were involved in parallel odor perception surveys and community-based air quality monitoring during peak odor events to determine spatial and temporal emissions patterns and levels of air pollutants. Surveys were web-based and asked about the time, date, location, and intensity of odors, while air quality testing was conducted to sample for volatile organic compounds (VOCs) and formaldehyde. Odors were most frequently observed on Wednesdays and Thursdays, and odors of the strongest intensity at the smallest distance from the foundry. Of the 57 VOCs analyzed in air samples, 24 had concentrations above the detection limit of 0.5 ppb. Formaldehyde was detected in all samples. Only one VOC exceeded statutory limits—methylene chloride—and it was detected in all samples. While CBM is limited in its capacity to be a reliable and standalone method of data collection, it is a promising approach that provides more comprehensive knowledge of environmental conditions, while empowering and spreading knowledge to community members about local issues. A combination of CBM with traditional methods could collect data with the potential to be more effective than either method alone.

KEYWORDS

participatory science, fenceline community, steel casting, volatile organic compounds, environmental health risk

INTRODUCTION

In the United States, enough hazardous air pollution is emitted to place over 92% of the population at an increased risk of developing respiratory diseases relative to an area without industrial emissions, and 17% of the population is at an even higher risk (Overdevest and Mayer 2008). This highest risk category likely includes residents of communities living on the fencelines of industry who are directly exposed to emissions on a regular basis (Calvano 2007). Residents of these higher-risk areas may strongly believe that their community is exposed to hazardous pollution, and impacted communities have criticized government regulatory agencies for what they believe is an ineffective response to their claims and concerns. This sentiment stems from the belief that detection by experts is substandard due to lack of awareness or belief that there is a problem, a want of methods for exposure identification, and other institutional limits to science (McCormick 2012). Historically, government-run air quality monitoring has been overly focused on producing average concentrations of toxic chemicals over long periods of time, and resource limitations did not provide an accurate assessment of resident exposures to health hazards (Russell 1992). This poor response to the situation disproportionately affects poor and marginalized communities with lower property values that are adjacent to industrial facilities (Overdevest and Mayer 2008).

A widespread industrial process in the United States is metal casting; as of 2014 there were 1,978 facilities in operation (Modern Casting 2014). Steel is one of the most common metals used in the industry, yet steel casting has not been subject to much scrutiny by industrial ecologists, and there is little consensus on its environmental and health impacts (Dalquist and Gutowski 2004). Emissions vary among steel foundries, but generally include various hazardous air pollutants, including polycyclic aromatic compounds (PAHs), volatile organic compounds (VOCs), airborne metals, and particulate matter (Joshi and Ravi 2005). This lack of consensus leaves communities bordering steel foundries at risk, due to the variation in and uncertainty about the nature of exposure at different sites. A data gap remains regarding what substances are present in steel foundry emissions on a case-by-case basis, and this deficit requires further investigation to ensure that those living along a particular industrial fenceline are not exposed to health hazards at dangerous levels.

To counteract institutional constraints on monitoring, novel methods have been used in recent years, employing community members directly in the data collection process. For problems of air quality, community-based monitoring (CBM) has been used in other communities around the United States to allow residents of impacted communities to conduct environmental testing and surveying as "citizen scientists" (Ottinger 2010). CBM specifically engages these citizen scientists in research design, data collection, and analysis of environmental concerns in their community, and addresses institutional downfalls in monitoring by providing an immediate, fine-grain, local assessment (McCormick 2012). Community residents are a valuable resource for determining air quality because they are aware of emissions patterns, are very invested in their homes and the health of their families, and are in a position to take real-time air quality samples at points of acute exposure (O'Rourke and Macey 2003). Residents deserve to have a voice in matters that affect their community, and CBM asserts their role in the decision-making process.

In University Village, the University of California at Berkeley's family housing community in Albany, California, there have been concerns for decades regarding potentially harmful air pollution from a nearby green sand casting facility named Pacific Steel Casting (PSC). Residents have reported strong intermittent industrial odors similar to burning plastic, and many are concerned about the perceived health risks arising from these observations. Not only is the odor a nuisance, but many residents and especially their children have reported experiencing eye, nose, and throat irritation, asthma, and exacerbated existing medical conditions. Notably, residents report that these symptoms disappear while living away from the area for brief periods. Consequently, there is a perceived link between an ostensible health risk and its physical presentations. No studies to date have comprehensively addressed emissions from Pacific Steel Casting; they have not targeted substances that could cause odors, and institutional constraints on monitoring have made it difficult to sample during peak odor events. Such limited sampling methods have produced data that fails to adequately document acute exposures and health risks faced by residents.

I conducted a concurrent odor study and air quality testing that employs methods of community-based monitoring and addresses monitoring constraints posed in the EH&S and BAAQMD studies. My central research question is: Can CBM methods of surveying and air quality testing collect data that improves upon institutional monitoring methods for documenting the causes of malodors and potential health risks in University Village? My main goals were to: (1) Determine temporal and spatial patterns associated with emission odors; (2) Analyze levels of volatile organic compounds and formaldehyde during peak odor events to determine if they reach concentrations that are hazardous to human health, and (3) Investigate how citizen science can inform ongoing, formal efforts to assess dangers posed to University Village residents. This study produced awareness of air quality and health risks in the community by addressing gaps left by institutional monitoring in the area, and further adds to the discourse regarding the efficacy of such methods in generating meaningful data, engaging residents in data collection, and making contributions to the political decision-making process.

METHODS

Study system

The University Village is a family housing community for the University of California at Berkeley located three blocks northwest of the Pacific Steel Casting foundry. It is a high-demand subsidized family housing community of over 900 residential apartments. The majority of people who live there are older undergraduates, graduate students, or postdoctoral students with children and/or spouses. Because of this, the Village houses a larger vulnerable population of pregnant women and young children than other areas. Children who live in the Village often attend public schools very close by—thus spending much of their day in the area exposed to local emissions and odors. The function of University Village as a temporary housing community causes residents to have a higher tolerance for health risks. While many are concerned about their possible exposure to hazardous air pollutants, they set this aside because they know they will move out soon. This high turnover has made it difficult to sustain efforts to address the issue of air pollution in University Village (T. Tipton and V. Plaks, *personal communication*).

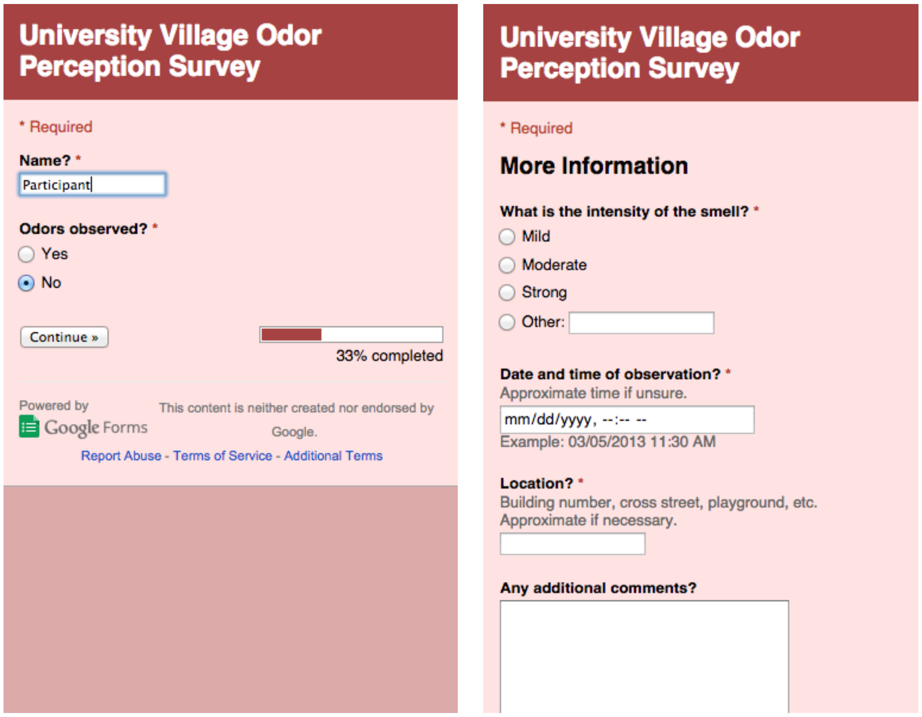
Data collection methods

To determine patterns in emission and air quality in University Village, I conducted parallel odor perception surveys and community-based air quality monitoring with residents during peak odor events.

Odor perception surveys

To collect data on factors associated with odor events, including time, date, location, and intensity, I recruited residents to participate in continuous online odor perception surveys. Recruitment methods included sending out informative emails to all residents by University Village Management, presentations at monthly Village Residents' Association meetings, and flyering door-to-door and at bus stops within the Village. Flyers and handouts from presentations contained important details about the study and residents' roles, background information on the problem, and my contact information. Participation averaged at around 30 households at any given time, and I recruited continuously throughout the year-long sampling period to account both for loss of residents who moved out of the Village and loss of interest.

Odor perception surveys were conducted between March 2014 and February 2015, and continuously provided data through a Google survey embedded into a website containing instructions, contact information, and links to further information about the issue (Figure 1). When residents contacted me with interest in participating in odor surveys, I sent them the link to the website to bookmark for easy access when they wanted to report odor events. Survey questions asked for: name, if odors were observed (yes/no), odor intensity (mild/moderate/strong/other—with text box), date, time, location within the village, and additional comments. Odor intensity was split into three levels instead of placed on a more detailed scale due to the nature of observations as informal and perception-based, and to maintain simplicity.



University Village Odor Perception Survey

* Required

Name? *

Participant

Odors observed? *

○ Yes

● No

Continue »

33% completed

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University Village Odor Perception Survey

* Required

More Information

What is the intensity of the smell? *

○ Mild

○ Moderate

○ Strong

○ Other:

Date and time of observation? *

Approximate time if unsure.

mm/dd/yyyy, --:-- --

Example: 03/05/2013 11:30 AM

Location? *

Building number, cross street, playground, etc. Approximate if necessary.

Any additional comments?

Figure 1. Web-based odor perception survey interface. Residents filled out their name, the intensity, date, time, and location of perceived odors, and additional comments.

Air quality monitoring

To collect data on air quality during peak odor events, I selected three residents to participate from the pool of those involved in odor perception surveys based on consistent interest and dedication to the study. I distributed seven 3-liter tedlar bags to test for 60 common volatile organic compounds (VOCs) and seven formaldehyde passive badge samplers (SKC UMEX 100) among the three participants. Two participants were given two sets, and one participant was given three sets of samples. One set consisted of one tedlar bag and one formaldehyde badge. During a moderate to severe odor event, participants took one set of samples; grab air samples for VOCs were instantaneous, and formaldehyde badges were left outside for a 24-hour exposure. Participants also kept logs of the date, location, and start and stop times for all samples. Once completed, samples were sent to ALS Environmental Laboratory in Salt Lake City, Utah for analysis. VOC samples were analyzed with EPA method TO-15, and formaldehyde samples with NIOSH method 2016.

Analysis

Odor perception surveys

To visualize and better understand emissions patterns, I used odor perception survey data to create several graphs and images. I explored several different topics: characteristics of participation throughout the study, the number of survey entries per day of the week, intensities of odors based on the day of the week, the times of day at which odors were reported, and finally, the locations where odors were perceived and the distances between the locations of odors and the foundry.

I first characterized participation throughout the study by creating a table that totaled the number of unique participants that entered odor data each month and the percentage of residents actively participating in a given month. I also determined the period of active participation in odor surveys for each participant by creating a Gantt chart. I then created bar charts that displayed the total number of odor entries by day of the week, and split up these totals by the amount of mild, moderate, and severe odor observations for each day. I further visualized odor intensity data for weekdays and weekends with pie charts that compared the percentages of each odor intensity reported out of the total. To explore the times of day at which odor reports occurred, I totaled the number of observations for each 4-hour period of the day overall and also split between weekdays and weekends and created bar charts. Finally, I used GPS coordinate data to create a heat map that served as an aid to see general emissions patterns in the area.

Air quality monitoring

To determine health implications of data collected on levels of volatile organic compounds and formaldehyde, I compared measured values to statutory limits. Data provided from the laboratory was compared with the U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS), the Office of Environmental Health Hazard Assessment's (OEHHA) Air Toxics Hot Spots Program, and California Proposition 65 Safe Harbor Levels.

I also researched and compiled the carcinogenicity rankings and developmental and reproductive toxicity potentials of each VOC analyzed. Cancer classifications were provided by the EPA Cumulative Risk Assessment (1986, 1996, 1999, 2005) and the International Agency for Research on Cancer (IARC). Developmental and reproductive toxicities were taken from the Office of Environmental Health Hazard Assessment's chronic and acute hazard indices (2003), and the EPA Integrated Risk Information System critical health effects. A full list is located in Appendix B; compounds with reproductive and developmental toxicities are highlighted in red.

RESULTS

Overall characteristics of participants

I found that participation levels in odor surveying varied throughout the course of the study from March 2014 through February 2015. While a total of 31 households were involved over the course of the study, the number that regularly engaged with surveys varied from month to month. Participation, determined by the number of participants that entered data into surveys each month, was highest during the two periods from March through May 2014 and July through September 2014, and lowest during the period between November 2014 and January 2015 (Table 1). This translates to a 22.6% participant data entry rate during the most active month, July 2014, and a 3.2% participant data entry rate during the least active month, January 2015 (Figure 2).

I also tracked each participant individually and found that at any given time, there were several participants actively participating in odor surveys (Figure 3). In the figure, participants who entered odor data at least one time during the study period are coded on the y-axis, with dates of participation on the x-axis. The period of active participation was calculated as the period of time between the first observation and the last observation, unless I was told that a participant was away for a period of time. Start and end dates of participation varied, but generally there was were several residents participating in surveys at any given point. It is important to note however, that these analyses of active participation do not include participants who actually were actively participating and remaining aware of potential odors but did not detect odors during a certain time period and did not fill out the survey.

Table 1. Summary of odor survey participation counts. The number of participants that reported odors at least one time during each given month in the study period. March 2014 to February 2015.

Total Number of Participants = 31	
Month	**Number of Participants that Reported Odors at Least One Time in the Given Month**
March 2014	5
April	6
May	5
June	4
July	7
August	6
September	5
October	3
November	2
December	2
January 2015	1
February	3

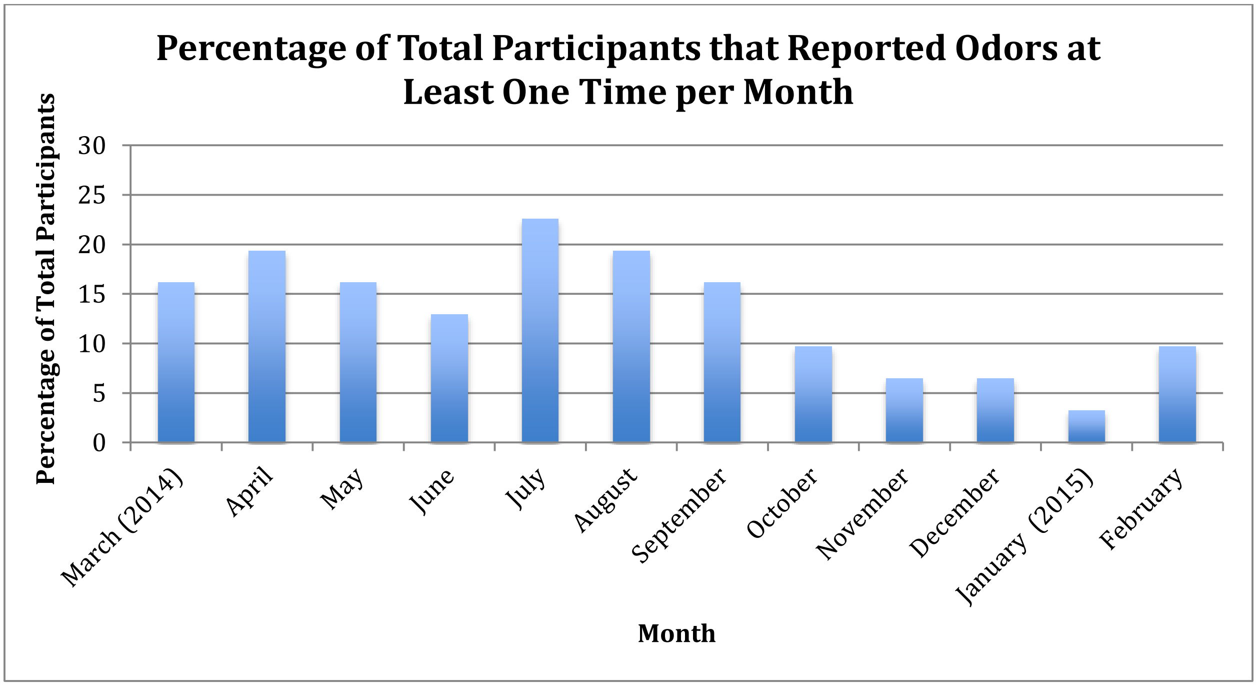


Figure 2. Percentage of total participants that reported odors at least one time per month. Bar chart of the months included in the yearlong study plotted against the percentage of participants actively entering data during each period.

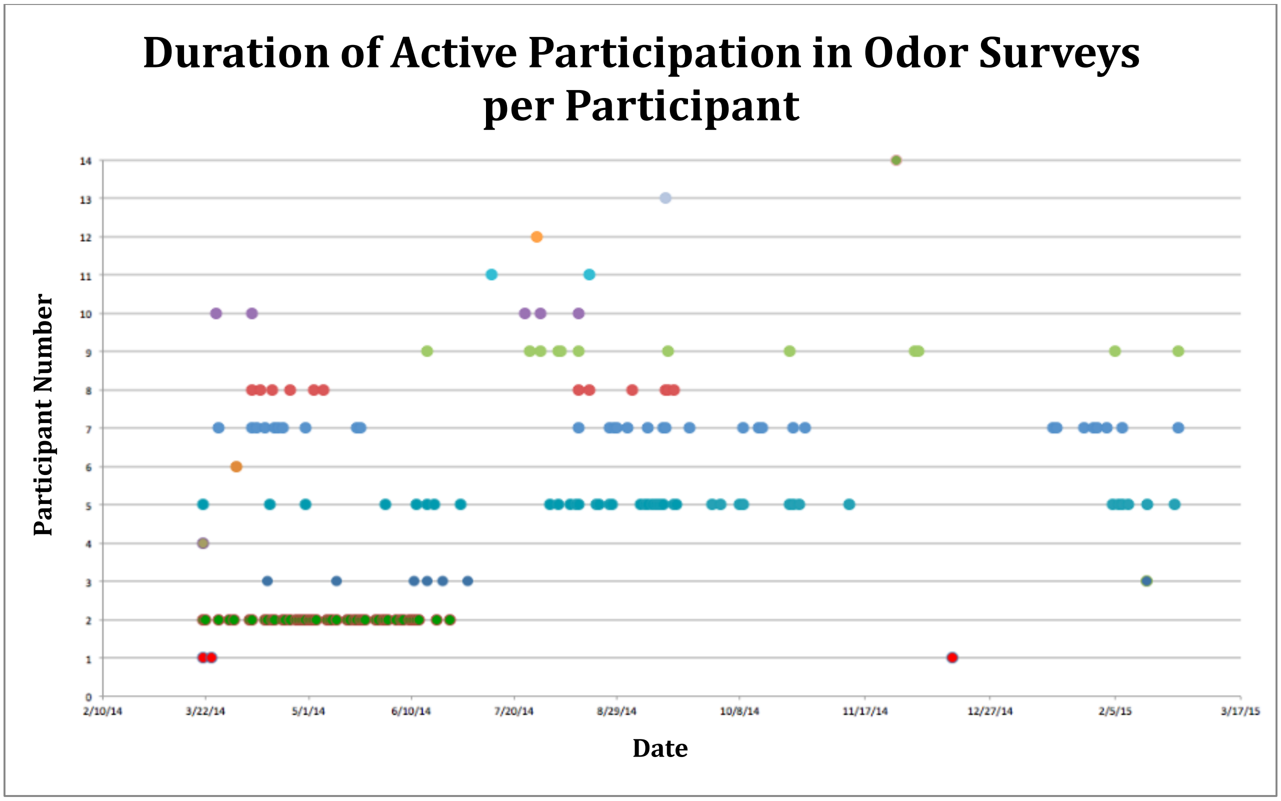


Figure 3. Duration of active participation in odor surveys per participant. Scatter plot of duration of participation by participant number (y-axis) over the year-long study period (x-axis).

Odor Perception Surveys

Temporal and intensity patterns

I found variation in daily odor reporting patterns and intensities (Figure 4). The greatest numbers of entries occurred on Wednesdays and Thursdays, while the lowest number of cumulative observations were on Saturdays and Sundays, with Sundays having the fewest. Mondays, Tuesdays, and Fridays typically featured moderate levels of observations. By further breaking down the number of observations by intensity, I found that the greatest number of observations of strong odors also occurred on Wednesdays and Thursdays, and that weekdays had a higher occurrence of strong odors and weekends had a higher occurrence of moderate odors (Figures 5 & 6). I then conducted a 3x2 chi-square test on intensity (mild, moderate, strong) vs. day (weekday or weekend), and found a p value of 0.02171 (Table 2). At a p=0.05 level, the difference in numbers of observations of odor intensities on weekdays and weekends is statistically significant.

I found that the majority of entries were in the mornings and evenings, from 8AM-12PM and after 6 PM (Figure 7). I also calculated total entries based separately on weekdays and weekends to search for possible variations, and found that they both displayed a nearly identical pattern both to each other and to the overall graph (Figures 8 & 9).

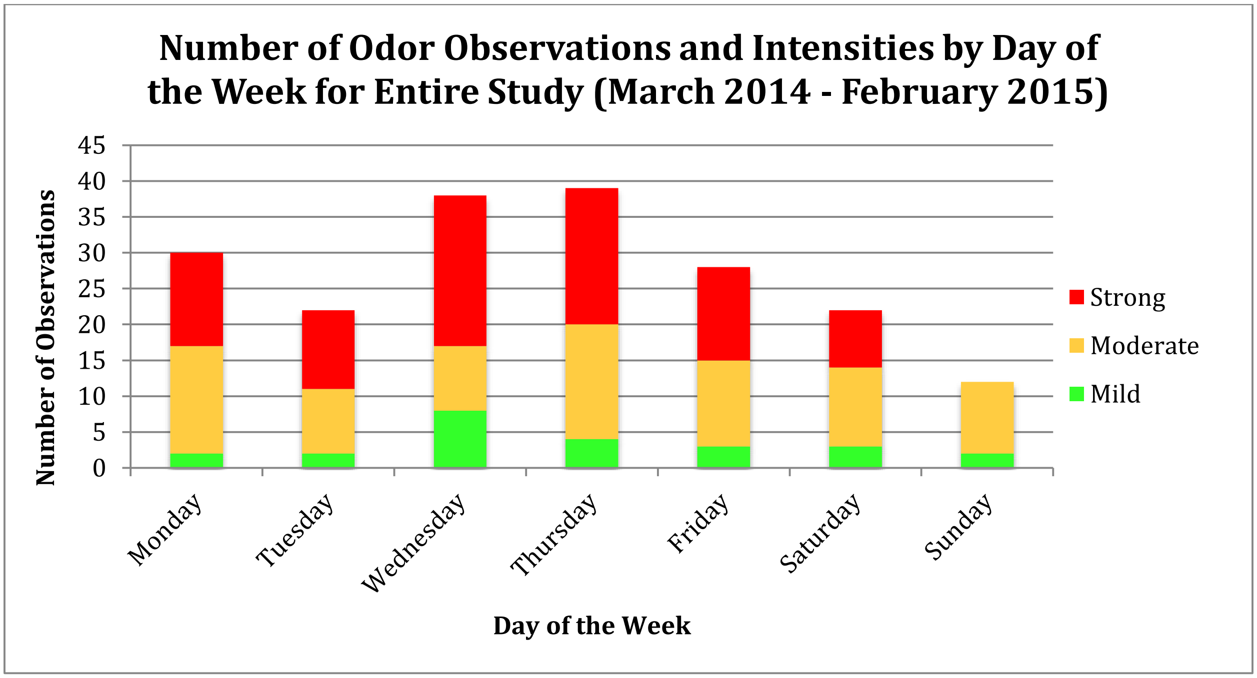
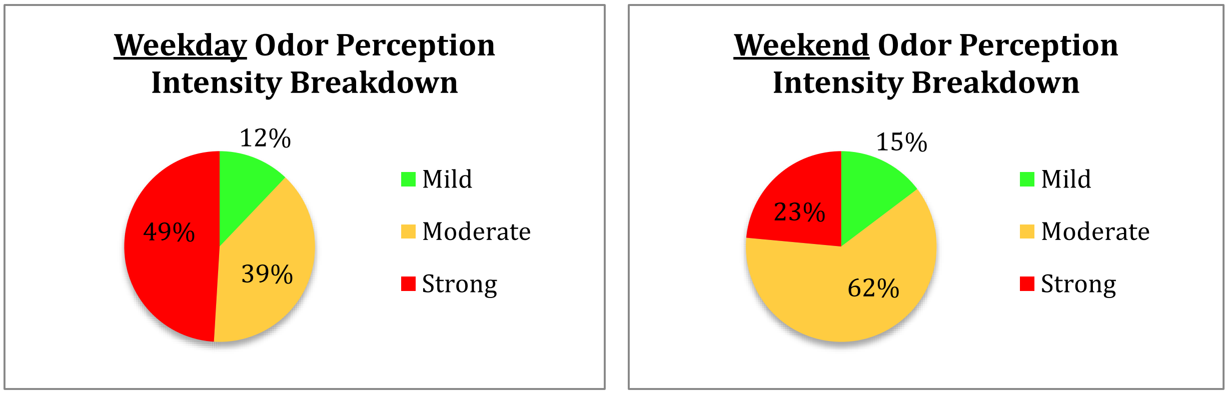


Figure 4. Number of odor observations and intensities by day of the week for entire study. Observations color-coded for intensity within each bar sum (Green - mild; Yellow - moderate; Red - strong).



Figures 5 & 6. Weekday & weekend odor perception intensity breakdown. Pie Charts highlighting percentages of odors occurring on weekdays and weekends, color-coded as mild, moderate, or strong (Green - mild; Yellow - moderate; Red - strong).

Table 2. Chi-square test of intensity of odors vs. weekdays or weekends. The p-value is 0.02171, and is statistically significant at the p=0.05 level.

	Mild	Moderate	Strong	**Total**
Weekday	19	61	77	157
Weekend	5	21	8	34
Total	24	82	85	**191**

Chi Square Test p-value: 0.02171

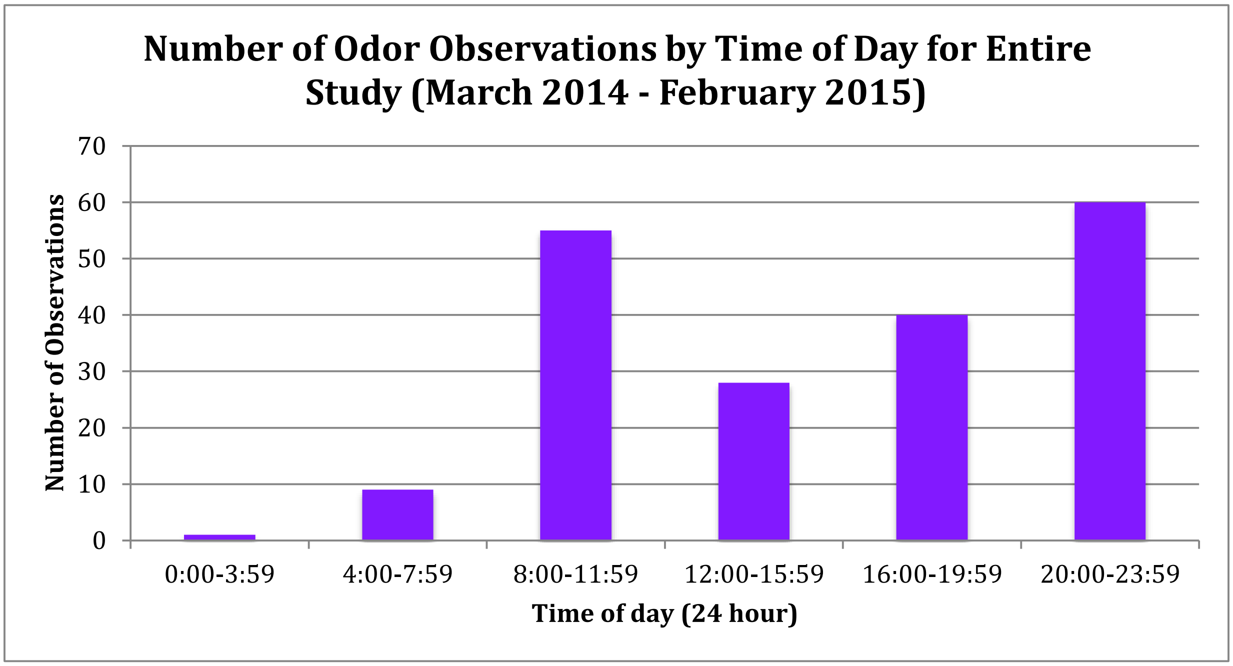
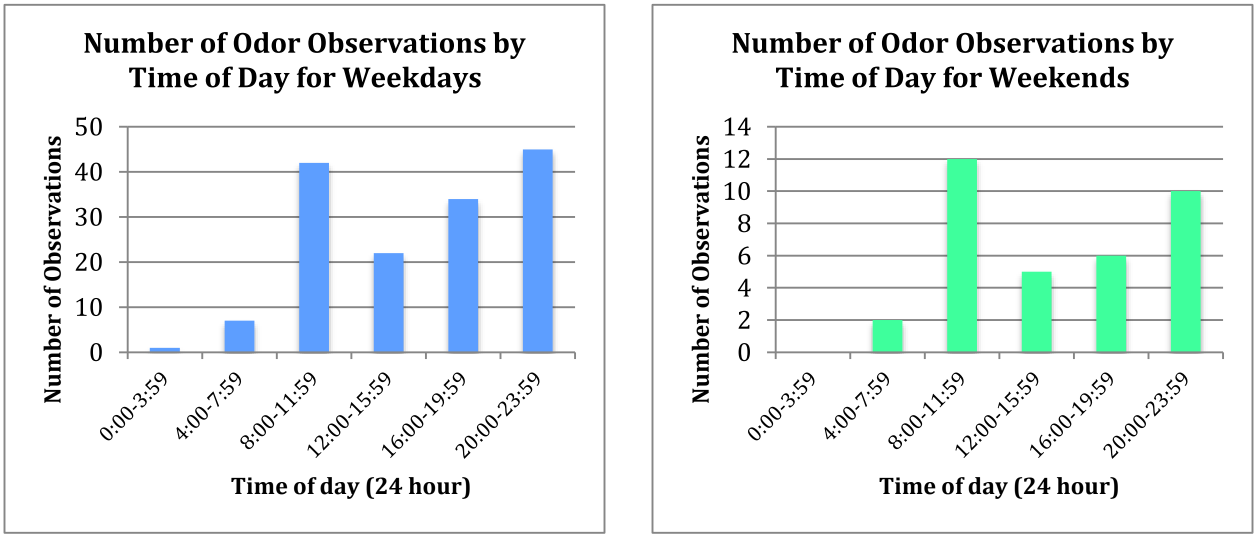


Figure 7. Number of odor observations by time of day for entire study. Time of day in 4-hour increments vs. number of total observations that occurred during each period during the year-long study duration.



Figures 8 & 9. Number of odor observations by dime of day for weekdays and weekends. Time of day in 4-hour increments vs. number of total observations that occurred during each period on weekdays and weekends during the year-long study duration.

Spatial patterns

Odor perception locations were spread throughout a wide area. The highest concentration of observations occurred within University Village, where all survey participants live, but high concentrations were found in other areas, especially along Gilman and 8th Streets, just south of University Village heading towards the University of California, Berkeley campus. Respondents reported odors as far Northwest as the Costco in Richmond, through University Village and the Gilman Street area, towards the intersection of Virginia Street and San Pablo Avenue in West Berkeley (Figure 10).

By converting all locations to GPS coordinates, I found that on average, the strongest odors were observed at the smallest distance from the foundry. This pattern is demonstrated by the overall locations of observations for mild, moderate, and strong odors, 0.610, 0.550, and 0.498 kilometers away from the foundry, respectively (Table 3). By calculating distances solely on the basis of weekdays versus weekends, the average distances to the foundry were very similar, at 0.526 and 0.557 kilometers away, respectively (Table 4). For reference, the center of University Village is 0.703 kilometers away from Pacific Steel Casting.

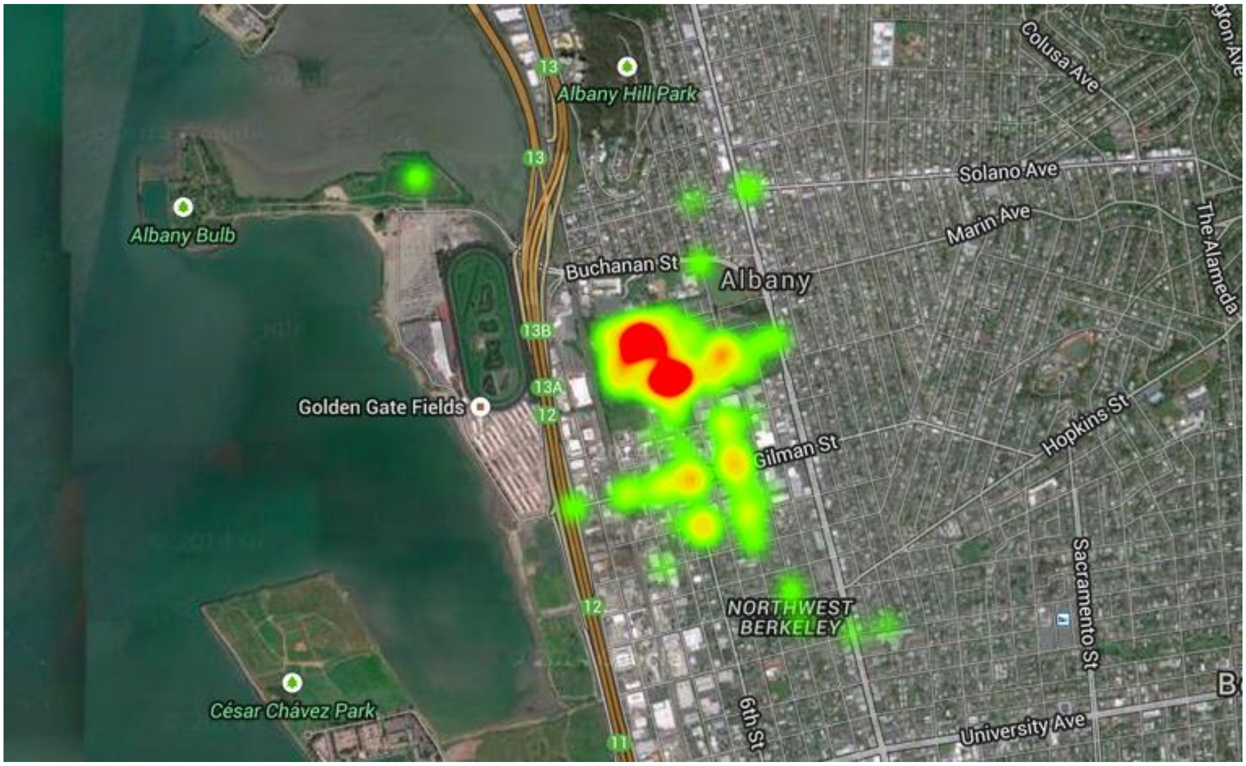


Figure 10. Heat map of malodorous observation locations and frequencies of observation. Perception locations in in northwest Berkeley and Albany, California. Entire study: March 2014 through February 2015. Red=high frequency of observations; yellow and orange=intermediate, green=low frequency. Image created by Google fusion tables.

Table 3. Summary of observation locations and distance to foundry. Intensity of odors observed (mild, moderate, and strong), and the average distance of observations to the foundry (kilometers).

Intensity of odors	Average Distance to Foundry (km)
Mild	0.610
Moderate	0.550
Strong	0.498

Table 4. Summary of observation locations by weekdays and weekends. Intensity of odors compiled into weekday and weekend observations categories and the average distance to the foundry (kilometers).

Weekday or Weekend?	Average Distance to Foundry (km)
Weekday	0.526
Weekend	0.557

Air quality monitoring

Overall detection of volatile organic compounds and formaldehyde

Chemical analysis of air samples found detectable levels for several volatile organic compounds (VOCs). Of the 57 VOCs analyzed in air samples, 24 were detected above the detection limit (42.1%) (Appendix A). In addition to VOCs, formaldehyde was detected in all samples, and 21 unique, tentatively identified compounds were detected overall in the samples. These tentatively identified compounds are compounds that I did not originally select for analysis, but the laboratory detected them at a high enough concentration that they were deemed important to report for future analysis.

Health risks – Carcinogenicity and developmental & reproductive toxicity

Through a comparison of recommendations from several agencies with VOCs detected in my data, several proved to be carcinogenic, and cause developmental and reproductive toxicity (Table 4). Cancer classifications were provided by the EPA Cumulative Risk Assessment (1986, 1996, 1999, 2005) and the International Agency for Research on Cancer (IARC). Developmental and reproductive toxicities are taken from the Office of Environmental Health Hazard Assessment's chronic and acute hazard indices (2003), and the EPA Integrated Risk Information

System critical health effects. Reproductive and developmental toxicities for each substance are highlighted in red (Appendix B). Air sample analysis found numerous compounds with developmental and reproductive toxicity potential. Six VOCs with concentrations above the detection limit in at least one sample fall into this category: (1) methyl ethyl ketone, (2) benzene, (3) cyclohexane, (4) methyl isobutyl ketone, (5) toluene, and (6) ethyl benzene (Table 3). However, none of the tested VOCs or formaldehyde reached concentrations that exceeded the non-carcinogenic reference concentration for chronic inhalation exposure (Table 5).

Table 5. List of analyzed substances with reproductive and/or developmental toxicity. Cancer classifications, other affected systems, test subjects, and sources of data for these substances are listed.

Substance	**Cancer classification (EPA CRA 1986, 1996, 1999, 2005, IARC 2002)**	**Toxicities & Target Organ Systems from Principal and Supporting Studies**	**Test Subject(s)**	**Source(s)**
Methyl ethyl ketone	D	Developmental (skeletal variety; eyes; respiratory system	mice	OEHHA 2003, EPA IRIS
Benzene	A	Reproductive and developmental; hematopoietic system; nervous system; alimentary tract; immune system; decreased lymphocyte count	humans	OEHHA 2003, EPA IRIS
Cyclohexane	Inadequate information	Reproductive and developmental	rats	EPA IRIS
Methyl isobutyl ketone	Inadequate information	Developmental – reduced fetal body weight, skeletal variations, and increased fetal death	rats	OEHHA 2003, EPA IRIS

Toluene	D	Reproductive and developmental; respiratory system; nervous system; eyes	unknown	OEHHA 2003
Ethyl benzene	D	Developmental; alimentary system (liver), endocrine system; kidney	rats and rabbits	OEHHA 2003, EPA IRIS

Health risks – Comparison of data to statutory limits

I found that by comparing my data with three different statutory limits, all compounds did not exceed safe limits except for one—methylene chloride (Table 6). Methylene chloride was found in all four of my samples, with a mean concentration of 0.3475 mg/m3 and a range of 0.16-0.47 mg/m3. It exceeded the OEHHA chronic Reference Exposure Level of 0.4 mg/m3 and the CA Proposition 65 No Significant Risk Level of 0.2 mg/m3.

Table 6. Average concentrations of VOCs and comparison of data to statutory limits. Non-carcinogenic reference concentrations for chronic inhalation exposure (RfC) from the U.S. EPA IRIS, OEHHA chronic Reference Exposure Levels, California Proposition 65 No Significant Risk Levels, and mean and range values for samples collected where values were above the minimum detection limit.

Substance	**IRIS Reference concentration for chronic inhalation exposure - RfC (mg/m^3)**	**OEHHA chronic REL (mg^m/3)**	**CA Proposition 65 No Significant Risk Level - NSRL (mg/m^3)**	**Mean (mg/m^3)**	**Range (mg/m^3)**
Dichlorodifluoromethane	N/A	~	~	0.0022	.0018-.0029
Methyl chloride	0.09	~	~	0.001195	.00098-.0011
Freon 114	N/A	~	~	~	~
Vinyl chloride	0.1	~	0.003	~	~
1,3-Butadiene	0.002	0.02	0.0004	~	~
Bromomethane	0.005	~	~	~	~
Ethyl chloride	10	30	0.15	~	~
Freon 11	N/A	~	~	0.001231927	.001-.0015
Freon 113	N/A	~	~	~	~
1,1-Dichloroethene	0.2	0.07	~	~	~
Acetone	N/A	~	~	0.04375	.038-.056
Carbon disulfide	0.7	0.8	~	~	~
Methylene chloride	0.6	0.4	0.2	0.3475	.16-.47
trans-1,2-Dichloroethene	N/A	0.07	~	0.003030711	ND-.0091

Methyl t-butyl ether	3	8	~	~	~
Vinyl acetate	0.2	0.2	~	~	~
Methyl ethyl ketone	5	~	~	0.004162362	ND-.0062
cis-1,2-Dichloroethene	N/A	0.07	~	~	~
1,1-Dichloroethane	N/A	0.07	0.1	~	~
Ethyl acetate	N/A	~	~	0.01958287	ND-.051
n-Hexane	0.7	7	~	0.0011675	.00062-.0022
Chloroform	N/A	0.3	0.04	~	~
Tetrahydrofuran	2	~	~	0.001237087	ND-.0027
1,2-Dichloroethane	N/A	0.07	0.01	~	~
1,1,1-Trichloroethane	7	~	~	~	~
Carbon tetrachloride	0.1	0.04	0.005	~	~
Benzene	0.03	0.06	0.013	0.000975	.0008-.0011
Cyclohexane	6	~	~	0.003512343	ND-.0065
Trichloroethene	0.002	0.6	0.08	~	~
1,2-Dichloropropane	0.004	~	0.0097	~	~
Bromodichloromethane	N/A	~	0.005	~	~
Heptane	N/A	~	~	0.002295748	ND-.0053
cis-1,3-Dichloropropene	0.02	~	~	~	~
Methyl isobutyl ketone	3	~	~	0.006410244	ND-.016
trans-1,3-Dichloropropene	0.02	~	~	~	~
1,1,2-Trichloroethane	N/A	~	0.01	~	~
Toluene	N/A	0.3	13	0.03525	.014-.078
2-Hexanone	0.03	~	~	~	~
Tetrachloroethene	0.04	0.035	~	0.001542621	ND-.001
Dibromochloromethane	N/A	~	~	~	~
1,2-Dibromoethane	0.009	~	~	~	~
Chlorobenzene	N/A	1	~	~	~
Ethyl benzene	10	2	~	0.00236586	ND-.0046
m,p-Xylene	0.1	0.7	~	0.007375	ND-.014
o-Xylene	0.1	0.7	~	0.002485834	ND-.0055
Styrene	1	0.9	~	0.002858111	ND-.0061
Bromoform	N/A	~	0.064	~	~
1,1,2,2-Tetrachloroethane	N/A	~	0.003	~	~
4-Ethyl toluene	N/A	~	~	0.001077502	ND-.001
1,3,5-Trimethylbenzene	N/A	~	~	0.001121864	ND-.00074
1,2,4-Trimethylbenzene	N/A	~	~	0.001561864	ND-.0025
1,3-Dichlorobenzene	N/A	~	~	0.003545844	ND-.0096
1,4-Dichlorobenzene	0.8	3	0.02	0.004213896	ND-.010
Benzyl chloride	N/A	~	0.004	~	~
1,2-Dichlorobenzene	N/A	~	~	~	~
1,2,4-Trichlorobenzene	N/A	~	~	~	~
Hexachloro-1,3-butadiene	N/A	~	~	~	~

DISCUSSION

The motivation for my study was to determine whether CBM methods improved upon data collection for determining air quality in University Village, as prompted by industrial emissions from the nearby Pacific Steel Casting foundry. The study yielded data that provided information on emissions patterns that is suggestive but inconclusive for determining the health impacts of PSC and the efficacy of citizen science. While citizen science has benefits, there are certain uncontrollable factors and human error considerations that must be taken into account when partnering with residents for data collection. Although the merits of citizen-based data collection relative to traditional monitoring remain open for debate, I was able to see overarching patterns in emissions from survey data containing odor perception information from residents that weren't evident from institutional monitoring efforts. These limitations in formulating a conclusion are in large part due to the small volume of samples employed and somewhat rudimentary sampling techniques selected through time and cost constraints presented through the design of the project, limitations in selecting which compounds to analyze, and the possibility that air quality does not pose a real risk to the health of residents.

Participation characteristics and the role of citizen science

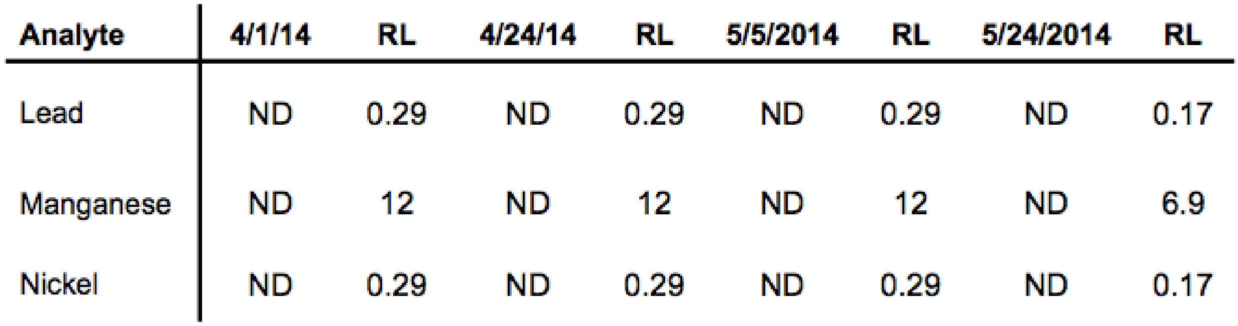
Citizen science methods of data collection are effective for understanding issues at a more personal and targeted level as compared to traditional monitoring methods, but it is unclear if citizen scientists can collect standalone data that produces meaningful results and definitive answers to questions of environmental quality and health risk. This study was prompted by a parallel study conducted by UC Berkeley's Office of Environmental Health and Safety (EH&S) of odorless airborne heavy metals (lead, manganese, and nickel) through an outside contractor using traditional monitoring methods. In contrast I approached the issue by using citizen science framework for data collection. Below, I highlight both the benefits and drawbacks of the citizen science framework that was used as the data collection method for my study.

Pros

There are several advantages of citizen science that allow this method to produce data that is different from a traditional approach. This approach can be valuable for understanding perspectives of community members and for documenting their perceptions of an issue surrounding environmental quality. Citizen science has been employed in a number of different types of studies that sought specifically to evaluate the accuracy of data collected by non-professional scientists. Citizen scientists, especially those who are older and more educated, on average collect fairly accurate data (Delaney et al. 2008 and Galloway et al. 2006). This bodes well for my data, which was conducted in large part by adults who are currently pursuing graduate degrees or postdoctoral work and their families. Additionally, the involvement of citizen scientists in the data collection process can assist with government monitoring efforts of tracking environmental conditions, species compositions, and more, since government agencies often possess limited budgets and personnel (Galloway et al. 2006). Such involvement can serve as an opportunity for students to fulfill academic requirements, gain valuable experience, and become more involved in their community. As a result, citizen science produces data that has the potential to be more of a call-to-action to local issues than professionally-collected data, because it directly educates and involves those who are affected by these problems (Gasteyer and Flora 2000).

In the case of University Village, this engagement effect was evident in the non-random sampling during peak odor events as opposed to randomized, ambient data collected by EH&S. Although the original plan was to sample 24 times throughout the year, communication with EH&S about the project was limited due to the difficulty of communication with the outside contractor that conducted sampling and data analysis. I hoped to obtain information about all 24 samples, yet only received the analysis from four samples, taken between April and May 2014. In all four samples, airborne concentrations of lead, manganese, and nickel were not detected above the detection limit (Table 7). While this study may in reality demonstrate that there is no elevated health risk in University Village from heavy metals, it is possible that the study was limited by the ambient, randomized nature of sampling or from a study design that did not target the appropriate compounds. Another important factor to take into consideration is that while regulators and contractors work mainly during business hours, residents took targeted samples or filled surveys whenever they were home or in the general vicinity and recognized malodors. Over half of odor perception entries—100 of 193 – were reported at night between 8:00pm and 12:00 am. This employment of citizen scientists translated to data that represented occurrences of and air quality levels specifically during what were perceived by residents as peak odor and emissions events during a broader portion of both traditional working and non-working hours.

Table 7. EH&S study analysis of airborne heavy metals. All units in ug/m^3. RL=Reporting Limit; minimum concentration of analytes that can be detected by sampling equipment. ND=Not Detected; analytes not detected above the reporting limit.



Analyte	4/1/14	RL	4/24/14	RL	5/5/2014	RL	5/24/2014	RL
Lead	ND	0.29	ND	0.29	ND	0.29	ND	0.17
Manganese	ND	12	ND	12	ND	12	ND	6.9
Nickel	ND	0.29	ND	0.29	ND	0.29	ND	0.17

Cons

While citizen science succeeds at both providing more targeted data and empowering and educating community members on issues that are relevant to them, it is hard to use as standalone information that provides any conclusive results. Budgetary restrictions led me to focus on testing of air quality that was tailored to emissions specifically from Pacific Steel Casting, while in reality the neighborhood is in close proximity to an interstate highway and several other industrial operations that could degrade air quality. Students who attend schools close to major roads have statistically significant increased occurrences of asthma and bronchitis as compared to students who attend upwind and more distant schools, which indicates that residences that likewise are in close proximity to major roads might face similar health risks (Kim et al. 2004). Many parents of young children reside in University Village and report increased rates of respiratory conditions, and this study calls into question whether this is caused by foundry emissions, traffic-related emissions, or a combination. While targeting testing to a specific source is beneficial and somewhat necessary for citizen science, it does not rule out or investigate other mobile sources and smaller emitters in the area (Morello-Frosch et al. 2001). This is not to say that professional sample collection does not also face these same issues, but such operations possess greater access to materials and trained knowledge to possibly rule out more unknowns.

Another issue with this type of sampling is that it often does not provide any ambient or "control" data of conditions to compare with, making it difficult to contextualize health hazards from the foundry and separate this data from overall air quality in the area. Additionally, odor perception data collected by citizen scientists is very subjective. Citizen scientists are better at estimating relative levels of measured substances rather than absolute levels, so their opinions about odor intensity and their perceived health risk are entirely based upon the relative strength of odors they experience compared to prior observations (Bonney et al. 2009). Since I possessed a small budget, I was only able to instruct residents to sample directly during times of strong perceived odors, as opposed to including sample collections during times where no odors were perceived. In contrast, official monitoring programs have greater access to larger budgets, and sample for longer durations and at times where malodors are not detected. This improved availability of funding and sampling materials allow such programs to attain more comprehensive data during multiple scenarios. For example, while data collected by EH&S in University Village failed to collect information about air quality during peak odor events, samplers collected random 24-hour averages, which on the whole provided more of a general sense of average air quality in the area.

On top of these issues, there are inherent problems that arise from using citizen scientists for data collection as opposed to trained professionals. Several samples were lost or broken by participants of my study, which is difficult to work around on a limited budget. Additionally, there is no way to truly know if all samples were taken with the proper techniques. It is also unclear whether patterns in emissions observations were skewed to reflect participants' travel patterns and physical sensory sensitivity to malodors. Data collected by citizen scientists is valuable for obtaining data that more accurately documents their experiences and observations, but this method would benefit from greater resources and clear ambient information in studies where this data would apply.

Synthesizing citizen science with traditional monitoring

It is evident that citizen science as a standalone method of data collection in this study had several downsides that are inherent with employing untrained residents as opposed to professionals for data collection. However, traditional monitoring—such as the study sponsored by EH&S—

has also been criticized as producing data that residents do not view favorably because it does not truly reflect the conditions that they experience. A combination of these two frameworks could create solutions with the potential to be more effective than either method alone. For example, in 1984, Denver, Colorado did not meet the federal ambient air quality standards for ozone and carbon monoxide as dictated by the 1977 Clean Air Act. The EPA used a state implementation plan that required public participation in all phases of the air quality planning process, created a citizens' task force, and ran public workshops and hearings. The Clean Air Task Force was comprised of state legislators, local governments, neighborhood organizations and many more groups (Stewart et al 1984). Some examples include the more recent Deepwater Horizon oil spill into the Gulf of Mexico and the involvement of nongovernmental organizations such as the Louisiana Bucket Brigade, and programs sponsored by the Cornell Laboratory of Ornithology for data collection involving bird counts, breeding-season and species surveys, and more (McCormick 2012 and Bonney et. al 2009). This type of planning has existed and been successfully implemented for over three decades, yet has not been employed in the West Berkeley area. By combining citizen science methods with traditional monitoring methods and facilitating communication between both parties, the personalized, targeted information collected by citizen scientists can be combined with the legislative power and greater resources of traditional monitoring to produce data that is both reliable and accurately describes local problems.

Odor survey data

Odor survey data provided greater insight into emissions patterns than traditional monitoring strategies by providing continuous logging of intensity, time, and location of perceived odors over the year-long study period. The study period yielded over 200 positive entries detailing observations of odor emissions events, and further analysis showed that the results were intuitive overall. Monthly fluctuations in participation showed some relationship with the UC Berkeley academic calendar, with the lowest participation rates coincident with winter and summer holidays. Location and intensity data described a pattern in which on average, the strongest odors were perceived at the closest proximity to the foundry, followed by moderate odors, and the mildest odors were perceived at the greatest distances. Additionally, the most odors were perceived in the mornings and evenings on both weekdays and weekends, but not in the middle of the day. This pattern lends further credit to citizen science being a useful tool for data collection, because it allows for the data collection to continue outside of normal business hours of regulators and contractors. While this same pattern held on weekends, the raw numbers of entries on Saturdays and Sundays could possibly reflect more time spent by residents outside of the Village on these days, as well as production schedules set by the foundry.

Air quality monitoring data

Air quality monitoring data of volatile organic compounds and formaldehyde was inconclusive, but provided important background data that could inform future investigation of air quality in the area. Federal standards that I employed from the U.S. Environmental Protection Agency's Integrated Risk Information System (EPA IRIS) and the Office of Environmental Health Hazard Assessment's chronic reference exposure levels (OEHHA chronic RELs) were the least stringent. I found that none of the average levels or range limits of compounds detected exceeded EPA IRIS reference concentrations, and none but one compound—methylene chloride—exceeded the OEHHA chronic REL. In contrast, California state levels from Proposition 65 Safe Harbor Levels of air toxics are more stringent than federal levels, and describe lower acceptable concentrations of air toxics for health risks towards humans. Similar to the federal standards, methylene chloride was the only compound that exceeded state levels, but it exceeded these standards by a greater amount. The EPA IRIS classifies methylene chloride is classified as a B2 probable carcinogen, with effects on the cardiovascular and nervous systems (EPA IRIS). This study could indicate the value of a future study with greater accuracy and statistical power, of chronic levels of methylene chloride to determine if they are of major concern.

Limitations and future directions

The University Village community

The community of residents living at University Village is demographically different from its West Berkeley surroundings, and presented its own benefits and challenges to citizen science and the data collection process. It is generally a very well educated group of people comprised predominantly graduate and postdoctoral students at UC Berkeley and their families. I found that some of the most active participants of my study come from scientific and especially environmental health or public health backgrounds—people who were generally predisposed towards these types of projects—making my job of recruiting a lot easier than it otherwise would be. This background knowledge possessed by several residents also could have had positive implications for the accuracy and precision of the data that they collected, as opposed to residents without this relevant background. Another unique characteristic of the University Village community is that it is very temporary, which serves as a disincentive for residents to become involved in these types of issues. Many residents have expressed concern over potential adverse health effects from foundry emissions, but many are busy and only reside in the Village for several years at most. This temporary nature of the community makes it very hard to sustain interest in an issue with a long timeframe, and to continuously transfer interest and knowledge to new residents adds time and budgetary costs to the monitoring plan. While these observations are very important to note specifically for the University Village community, they will affect other citizen science projects differently—where communities are connected solely by geography and not by a larger organization such as a university that creates a skew toward certain characteristics among its residents. A general-population community will most likely lack the advantages of a highly educated population with residents who have background interests in the study field, but will possess the advantage of a more permanent base of citizen scientists.

Future studies of the University Village should not only focus on compounds such as methylene chloride that potentially pose the highest risk to residents, but also a wider range of analytes from multiple industrial and nonpoint sources. Additionally, a study that includes the adjacent West Berkeley community that surrounds the foundry and other industries would create a larger study population. I recommend future studies in other areas to include residents from multiple communities and diverse backgrounds in the same neighborhood to become involved in citizen science efforts. This potentially has the effect of both balancing out the limitations in participation among different groups and allowing data to be collected that represents the experiences of a broader set of individuals.

Outreach and resources

While online surveys only held a time cost through set-up and outreach, the air quality monitoring aspect of this project was cost-intensive and required more effort and training for participants than the online surveys, greatly limiting the amount of data that could be collected and the conclusions that could be made. There was a tradeoff between the online survey, which was an easy task with more participants involved, and air quality monitoring—a harder task that involved fewer people and produced fewer data points. The effects of this tradeoff would not have been as great if the residents were able to devote an unlimited amount of time to the study, and if funding and outreach efforts were increased. Improved outreach efforts could increase the number of participants interested in the study as well as the amount of time they would be willing to allocate to data collection by emphasizing the project's objectives and importance, and a larger budget could support more samples spread across a larger participant pool with greater statistical significance. This larger pool of participants would also minimize the impact of losses of residents when they move out of the Village, and would reduce monthly fluctuations in active participation to gain more data that is and more evenly distributed over time. Additionally, the online surveys would benefit from more participants, because they would provide more variety in locational data and minimize outliers in participation, which results when a small group of participants that submit survey entries at a much higher frequency than others. Another limitation that I experienced with my study was that it only focused on emissions from a major point source emitter, and I lacked the resources to consider pollution from smaller emitters and non-point pollution from other sources, such as the nearby highway. Overall, better outreach and monetary resources could lead to a larger participant pool and a larger number of samplers distributed among them. This greater volume of samples and participants would in effect have the potential to produce data with smaller grain and wider extent—the locations of their homes would provide greater variety and spatial coverage of the neighborhood as a whole.

Broader implications

Despite its limitations, citizen science is a promising method of data collection that provides more comprehensive knowledge of environmental conditions than provided solely by traditional monitoring methods, while empowering and spreading knowledge to community members about issues that are important to them. Community members can become more aware of issues that directly affect them, and feel that they have a more responsive outlet for expressing their concern in their roles as citizen scientists. Citizen science has implications on policy-making and data collection that can assist the traditional monitoring process of environmental quality—by providing complementary information that indicates potential problem areas and compounds, bypassing institutional limitations of budget and lack of professionals. Increasing future collaboration between government agencies and communities to form strategies that tackle large data collection projects related to many aspects of environmental quality can provide a great learning and community engagement experience that helps governments ease the burden on their limited resources and allow the creation of solutions that are in the best interests of all of those involved

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REFERENCES

Bonney, R., C.B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K.V. Rosenberg, and J. Shirk. 2009. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. BioScience 59: 977-984.

Calvano, L. 2008. Multinational Corporations and Local Communities: A Critical Analysis of Conflict. Journal of Business Ethics 82:793-805.

Dalquist, S. and T. Gutowski. 2004. Life Cycle Analysis of Conventional Manufacturing Techniques: Sand Casting. Proceedings of IMECE04 ASME International Mechanical Engineering Congress and Exposition: 1-11.

Delaney, D.G., C.D. Sperling, C.S. Adams, and B. Leung. 2008. Marine Invasive Species: Validation of Citizen Science and Implications for National Monitoring Networks. Biological Invasions 10:117-128.

Galloway A.W.E., M.T. Tudor, and W.M. Vander Haegen. 2006. The Reliability of Citizen Science: A Case Study of Oregon White Oak Stand Surveys. Wildlife Society Bulletin 34:1425-1429.

Gasteyer, S., and C.B. Flora. 2000. Measuring ppm with Tennis Shoes: Science and Locally Meaningful Indicators of Environmental Quality. Society & Natural Resources 13:589-597.

IARC [International Agency for Research on Cancer]. 2002. Monographs on the Evaluation of Carcinogenic Risks to Humans. World Health Organization. 82. IARCPress, Lyon, France.

Kim, J.J., S. Smorodinsky, M. Lipsett, B.C. Singer, A.T. Hodgson, and B. Ostro. 2006. Traffic-related Air Pollution near Busy Roads: The East Bay Children's Respiratory Health Study. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, and Atmospheric Sciences Department and Indoor Environment Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley California 520-526.

McCormick, S. 2012. After the Cap: Risk Assessment, Citizen Science and Disaster Recovery. Ecology and Society 17:31.

Morello-Frosch R., M. Pastor, and J. Sadd. 2001. Environmental Justice and Southern California's "Riskscape": The Distribution of Air Toxics Exposures and Health Risks Among Diverse Communities. Urban Affairs Review 36: 551-578.

O'Rourke, D., and G. Macey. 2003. Community Environmental Policing: Assessing New Strategies of Public Participation in Environmental Regulation. Journal of Policy Analysis and Management. 22:383-414.

OEHHA [Office of Environmental Health Hazard Assessment]. 2012. Proposition 65 Safe Harbor Levels: No Significant Risk Levels for Carcinogens and Maximum Allowable Dose Levels for Chemicals Causing Reproductive Toxicity. A report of the Reproductive and Cancer Hazard Assessment Branch, California Environmental Protection Agency.

OEHHA [Office of Environmental Health Hazard Assessment]. 2003. Air Toxics Hot Spots Program Risk Assessment Guidelines. The Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments. California Environmental Protection Agency, Oakland, California, USA.

Ottinger, G. 2010. Buckets of Resistance: Standards and the Effectiveness of Citizen Science. *Science, Technology & Human Values* 35: 244–70.

Overdevest, C., and B. Mayer. 2008. Harnessing the power of information through community monitoring: Insights from social science. Texas Law Review 86 (7):1493-526.

Russell, C.S. 1992. Monitoring and Enforcement of Pollution Control Laws in Europe and the United States. Pages 195-219 *in* Pethig, Rüdiger, editor. Conflicts and Cooperation in Managing Environmental Resources. Springer Berlin Heidelberg, Germany.

"Steady Rebound from Recession." Modern Casting Magazine. American Foundry Society Jan. 2014: 23-27. Online.

Stewart, T.S., R.L. Dennis, and D.W. Ely. 1984. Citizen Participation and Judgement in Policy Analysis: A Case Study of Urban Air Quality Policy. National Center for Atmospheric Research. Policy Sciences 17:67-87.

US EPA [U.S. Environmental Protection Agency]. 1986, 1996, 1999, 2005. Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington D.C., USA.

APPENDIX A: OVERALL ANALYTE DETECTION

Table A1. Summary of analyte detection – Volatile organic compounds, formaldehyde, and tentatively identified compounds . List of all substances analyzed, and detection in at least one sample above the detection limit (Yes/No). 57 volatile organic compounds, 21 tentatively identified compounds, and formaldehyde.

Substance	Detected in at least one sample above the detection limit? (Yes/No)
------------------**VOLATILE ORGANIC COMPOUNDS**--------------------	
Dichlorodifluoromethane	YES
Methyl chloride	YES
Freon 114	NO
Vinyl chloride	NO
1,3-Butadiene	NO
Bromomethane	NO
Ethyl chloride	NO
Freon 11	YES
Freon 113	NO
1,1-Dichloroethene	NO
Acetone	YES
Carbon disulfide	NO
Methylene chloride	YES
trans-1,2-Dichloroethene	NO
Methyl t-butyl ether	NO
Vinyl acetate	NO
Methyl ethyl ketone	YES
cis-1,2-Dichloroethene	NO
1,1-Dichloroethane	NO
Ethyl acetate	YES
n-Hexane	YES
Chloroform	NO
Tetrahydrofuran	YES
1,2-Dichloroethane	NO
1,1,1-Trichloroethane	NO
Carbon tetrachloride	NO
Benzene	YES
Cyclohexane	YES
Trichloroethene	NO
1,2-Dichloropropane	NO
Bromodichloromethane	NO
Heptane	YES
cis-1,3-Dichloropropene	NO
Methyl isobutyl ketone	YES
trans-1,3-Dichloropropene	NO
1,1,2-Trichloroethane	NO
Toluene	YES
2-Hexanone	NO
Tetrachloroethene	YES
Dibromochloromethane	NO
1,2-Dibromoethane	NO
Chlorobenzene	NO
Ethyl benzene	YES
m,p-Xylene	YES
o-Xylene	YES
Styrene	YES

Bromoform	NO
1,1,2,2-Tetrachloroethane	NO
4-Ethyl toluene	YES
1,3,5-Trimethylbenzene	YES
1,2,4-Trimethylbenzene	YES
1,3-Dichlorobenzene	YES
1,4-Dichlorobenzene	YES
Benzyl chloride	NO
1,2-Dichlorobenzene	NO
1,2,4-Trichlorobenzene	NO
Hexachloro-1,3-butadiene	NO
--------------TENTATIVELY IDENTIFIED COMPOUNDS---------------	
Isobutane	YES
Acrolein	YES
Ethanol	YES
Isopropyl Alcohol	YES
Phenol	YES
1,2,4,4-Tetramethylcyclopentene	YES
Limonene	YES
Acetic acid, phenyl ester	YES
Decane, 3,7-dimethyl-	YES
Decane, 3,6-dimethyl-	YES
C12 Hydrocarbon	YES
Dodecane	YES
4-Bromofluorobenzene	YES
Propane	YES
C11 Hydrocarbon	YES
Pentane	YES
Heptane, 2,4-dimethyl-	YES
butane, 2-methyl-	YES
hexane, 3-methyl-	YES
C11 Hydrocarbon	YES
undecane, 5-methyl-	YES
------------------------------FORMALDEHYDE--------------------------------	
formaldehyde	YES

APPENDIX B: CARCINOGENICITY, DEVELOPMENTAL & REPRODUCTIVE TOXICITY

Table B1. Carcinogenicity and developmental and reproductive toxicities of all analytes. 57 VOCs, 21 tentatively identified compounds, and formaldehyde. Reproductive and developmental toxicities are highlighted in red.

Substance	Cancer classification (EPA CRA 1986, 1996, 1999, 2005, IARC 2002)	Chronic Inhalation Hazard Index Target Organ System(s) (OEHHA 2003)	Acute Hazard Index Target Organ System(s)	EPA Integrated Risk Information System (IRIS) Critical health effects from laboratory studies (RfC)

Dichlorodifluoromethane	inadequate information	~	~	
Methyl chloride	D	~	~	cerebellar lesions
Freon 114	inadequate information	~	~	
Vinyl chloride	A	~	nervous system; eyes; respiratory system	liver cell polymorphism
1,3-Butadiene	B2	reproductive system	~	ovarian atrophy
Bromomethane	D	~	~	degenerative and proliferative lesions of the olfactory epithelium of the nasal cavity
Ethyl chloride	inadequate information	alimentary system; developmental	~	delayed fetal ossification
Freon 11	inadequate information	~	~	
Freon 113	inadequate information	~	~	
1,1-Dichloroethene	C	alimentary system	~	liver toxicity (fatty change)
Acetone	not classifiable	~	~	
Carbon disulfide	inadequate information	nervous system; reproductive system	nervous system; reproductive/developmental	peripheral nervous system dysfunction
Methylene chloride	B2	cardiovascular system; nervous system	nervous system	hepatic effects (hepatic vacuolation)
trans-1,2-Dichloroethene	inadequate information	alimentary system	~	
Methyl t-butyl ether	inadequate information	alimentary system; eyes; kidney	~	increased absolute and relative liver and kidney weights and increased severity of spontaneous renal lesions (females), increased prostration (females), and swollen periocular tissues (males and females)
Vinyl acetate	inadequate information	respiratory system	~	nasal epithelial lesions
Methyl ethyl ketone	D	~	eyes; respiratory system	developmental toxicity (skeletal variations)
cis-1,2-Dichloroethene	not classifiable	alimentary system	~	
1,1-Dichloroethane	C	alimentary system	~	
Ethyl acetate	inadequate information	~	~	

n-Hexane	inadequate information	nervous system	~	Peripheral neuropathy (decreased MCV at 12 weeks) Rat subchronic inhalation study
Chloroform	B2	alimentary system; developmental; kidney	nervous system; reproductive/developmental	
Tetrahydrofuran	suggestive evidence	~	~	increased liver weight and centrilobular cytomegaly; narcosis
1,2-Dichloroethane	B2	alimentary system	~	
1,1,1-Trichloroethane	D	~	~	Performance on neurobehavioral tests
Carbon tetrachloride	B2	alimentary system; developmental; nervous system	alimentary tract; nervous system; reproductive/developmental	fatty changes in the liver
Benzene	A	developmental; hematopoietic system; nervous system	hematologic system; immune system; reproductive/developmental	decreased lymphocyte count
Cyclohexane	inadequate information	~	~	Reduced pup weights in the F1 and F2 generations, reproductive/developmental toxicity
Trichloroethene	2A	eyes; nervous system	~	decreased thymus weight in female B6C3F1 mice, increased fetal cardiac malformations in Sprague-Dawley rats, kidney cancer in humans, limited evidence of liver cancer
1,2-Dichloropropane	3	~	~	hyperplasia of the nasal mucosa
Bromodichloromethane	B2	~	~	
Heptane	D	~	~	
cis-1,3-Dichloropropene	B2	~	~	hypertrophy/hyperplasia of the nasal respiratory epithelium
Methyl isobutyl ketone	inadequate information	~	~	reduced fetal body weight, skeletal variations, and increased fetal death in mice and skeletal variations in rats
trans-1,3-Dichloropropene	B2	~	~	hypertrophy/hyperplasia of the nasal respiratory epithelium

1,1,2-Trichloroethane	C	~	~	
Toluene	D	developmental; nervous system; respiratory system	nervous system; eyes; respiratory system; reproductive/developmental	
2-Hexanone	inadequate information	~	~	motor conduction velocity of the sciatic-tibial nerve
Tetrachloroethene	2A	alimentary system; kidney	~	neurotoxicity in occupationally-exposed adults (reaction time, cognitive effects) Echeverria et al.; (color vision) Cavalleri et al. 1994
Dibromochloromethane	C	~	~	
1,2-Dibromoethane	B	~	~	nasal inflammation
Chlorobenzene	D	alimentary system; kidney; reproductive system	~	
Ethyl benzene	D	alimentary system (liver); developmental; endocrine system; kidney	~	Developmental toxicity Rat and Rabbit Developmental Inhalation Studies
m,p-Xylene	D	nervous system; respiratory system	eyes; respiratory system	impaired motor coordination
o-Xylene	D	nervous system; respiratory system	eyes; respiratory system	impaired motor coordination
Styrene	B2	nervous system	eyes; respiratory system	CNS effects
Bromoform	B2	~	~	
1,1,2,2-Tetrachloroethane	C	~	~	
4-Ethyl toluene	inadequate information	~	~	
1,3,5-Trimethylbenzene	inadequate information	~	~	
1,2,4-Trimethylbenzene	inadequate information	~	~	
1,3-Dichlorobenzene	D	~	~	
1,4-Dichlorobenzene	2B	alimentary system; kidney; nervous system; respiratory system	~	increased liver weights in P1 males
Benzyl chloride	B2	~	eyes; respiratory system	
1,2-Dichlorobenzene	D	~	~	
1,2,4-Trichlorobenzene	D	~	~	

Hexachloro-1,3-butadiene	C	~	~	
			~	
Isobutane			~	
Acrolein			eyes; respiratory system	nasal lesions
Ethanol			~	
Isopropyl Alcohol			~	
Phenol			eyes; respiratory system	
1,2,4,4-Tetramethylcyclopentene			~	
Limonene			~	
Acetic acid, phenyl ester			~	
Decane, 3,7-dimethyl-			~	
Decane, 3,6-dimethyl-			~	
C12 Hydrocarbon			~	
Dodecane			~	
4-Bromofluorobenzene			~	
Propane			~	
C11 Hydrocarbon			~	
Pentane			~	
Heptane, 2,4-dimethyl-			~	
butane, 2-methyl-			~	
hexane, 3-methyl-			~	
C11 Hydrocarbon			~	
undecane, 5-methyl-			~	
formaldehyde			eyes; immune system; respiratory	