2015 Special Toxics Study Report

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Contents

Executive Summary

The State of Utah has conducted air toxics monitoring as a part of the National Air Toxics Trends Stations (NATTS) program since 2002, with the monitors currently located at the Bountiful monitoring station. Over the past several years, the Division of Air Quality (DAQ) has been actively monitoring and analyzing the composition, trends, and distribution of hazardous air pollutants (HAPs) along the Wasatch Front. In 2015, as a part of this effort, DAQ designed and conducted a year-long special study aimed at characterizing HAP's distribution and seasonal trends across the Utah and Salt Lake valleys. The study entailed the installation of two additional air toxics monitors in Lindon and West Valley and intensifying the sample collection frequency at the Bountiful NATTS site to one-in-three days. With the exception of formaldehyde, discussed below, the HAPs monitored during the study were observed to be at or below the average national levels.

The analysis of 82 organic and 4 heavy metal species in approximately 300 samples collected over a full year pointed to four species in particular that merit further study. The study identified unusually high formaldehyde concentrations and uncommon seasonal trends at Bountiful. Wintertime observations of the pollutant suggest the potential for a significant source or sources of primary formaldehyde emissions. It is also possible that emissions of formaldehyde precursors might be contributing to the elevated levels of formaldehyde seen at the Bountiful monitor. Sources could include local refineries, painting or paint stripping operations, and/or other unidentified sources. Proximity to the Great Salt Lake may also enhance local formaldehyde concentrations. As the ambient HAP with the highest contribution to inhalation cancer risk on the Wasatch Front, as well as an important contributor to ozone and $PM_{2.5}$ formation, this finding makes a strong case for more rigorous study and stringent control.

Two additional species were observed at the Bountiful site. Acetaldehyde showed a strong correlation with formaldehyde concentrations. Another organic compound, methylene chloride, was detected with emission levels significantly above health screening levels. Currently, the source or sources of the methylene chloride emissions are unknown and further investigation is necessary.

Although significantly lower than the health screening level, West Valley PM_{10} data showed higher lead concentrations than was measured at either Bountiful or the Lindon monitor in Utah County. Possible sources of the elevated lead concentrations could be a residue from former lead smelters that existed in the area, the former Sharon Steel Corporation Superfund site, or current mining operations in the valley. It is also possible that the Rio Tinto/Kennecott tailing ponds could be contributing to the higher lead presence in the area.

A significant decrease (nearly 70%) in benzene concentrations was observed between 2002 and 2016 in West Valley. Benzene is a pollutant that is commonly observed in urban areas and is strongly associated with automobile exhaust. The large reduction in benzene concentrations over the past fourteen years at the West Valley monitor is a very positive development and suggests that cleaner automobile engine technology has been effective in reducing levels of this toxic chemical. While it is possible that there are

local primary benzene sources near the monitor that have reduced their emissions, it seems more likely that benzene concentrations in the area are associated with vehicle exhaust. Therefore, it would be reasonable to assume that benzene concentrations throughout the Wasatch Front have been reduced considerably over this same time period.

Further studies are necessary to identify the sources of formaldehyde, methylene chloride, and lead. Possible approaches to better understand the sources of these observations are described in the Discussion section of this report.

Introduction

The Environmental Protection Agency (EPA) has identified 187 HAPs that are associated with numerous adverse health effects including cancer and neurological, reproductive, developmental, and other health problems. These pollutants come from a wide variety of industrial, residential, and mobile sources and the health risk exposure thresholds associated with them are continually updated according to the most current toxicological and epidemiological research.

In 2000, DAQ began monitoring for HAPs in West Valley City. In 2003, the EPA established the National Air Toxics Trends Station (NATTS) network to satisfy the need for a long-term monitoring of HAPs using a consistent methodology. A network of 27 permanent urban and rural sites was developed across the US to observe the nationwide trends in ambient levels of HAPs. The goals of this network are to provide consistent, reliable HAPs data; observe the long-term trends in HAPs levels; assess the effectiveness of HAPs control policies for reducing health risks; and supply data for the creation of reliable HAPs inventory and associated models. The State of Utah has a single NATTS site that was established at the Bountiful monitoring station near Viewmont High School to replace and update the West Valley HAPs monitoring site.

Protecting public health by regulating the emissions of air pollutants is one of the major objectives for the DAQ. As a part of reaching this objective, in 2013 DAQ undertook a rigorous analysis of the HAPs data collected at the Bountiful site between 2003 and 2012. The study examined the long-term trends, pollutant levels, outlier events, and population exposure health risks. As part of this analysis, data from the Bountiful site was compared to concentrations from Phoenix, Arizona. The results indicated that 11 of 187 HAPs were regularly observed at the Bountiful site, ten of which were also observed in Phoenix. Eight of the HAPs were observed at higher concentrations in Phoenix than in Salt Lake City. Overall, the study indicated that, with the exception of formaldehyde which is discussed in more detail later in this report, the concentration of HAPs observed in the greater Salt Lake area corresponded well to those observed in Phoenix urban area.

In 2014, the Utah legislature allocated one million dollars to be used for air quality research to address specific problems in the state. A $110,000 study was funded from that appropriation to conduct a follow-up HAPs monitoring project detailed in this report. The project was a collaborative study between DAQ and the University of Utah designed to collect frequent HAPs samples for one year to complement

existing HAPs monitoring and included enhanced analysis techniques provided by the university. As part of the project, two additional HAPs monitoring sites were established in Lindon and West Valley for the duration of the study. The monitoring frequency was doubled from the standard one-in-six-day frequency at Bountiful resulting in a total of three HAPs monitoring sites operating every three days. The data obtained in this study augmented the original data analysis efforts in several ways. First, it enhanced the sample resolution by doubling it from a one-in-six to a one-in-three day frequency. This allowed for a more detailed look into day-to-day variation in HAPs levels throughout the two most significant pollution periods along the Wasatch Front: winter and summer. Second, the addition of two sites allowed a comparison of HAPs variation between Utah and Salt Lake Counties and provides the potential for further analysis to include source apportionment techniques. Third, the new West Valley site permitted an examination of the change between the current levels of HAPs and those that occurred from 2000 to 2002 in West Valley.

Method

The Utah NATTS site at Bountiful, DAQ's primary toxics data gathering site, was supplemented by two additional sites: West Valley and Lindon. Both additional sites were equipped with Partisol 2025 instruments for sequential PM_{10} monitoring, as well as an ATEC 2200-2 Toxic Air Sampler for simultaneous carbonyl and volatile organic compound (VOC) sample collection. The PM_{10} samples were collected on the standard 47mm Teflon filters. To avoid interference from barcode ink during analysis, unmarked filters were used. All the sites operated on the standard 2015 EPA 1-in-3 day sampling schedule.

The West Valley site was located at the Air Monitoring Center (AMC), approximately two miles from the previous toxics monitoring site that was operational in West Valley between 2000 and 2002. Because of the shelter temperature and sampling line restrictions, the toxics air sampler was installed inside a sampling shed at the rear of the center. A single-port glass manifold attached to a small electrical blower was used to minimize residence time during VOC and carbonyl sampling. Clean, stainless steel tubing was used for the sampling lines between the manifold and the sampler. The particle sampler was installed on the roof of the AMC building to avoid obstructions during sampling. The total horizontal distance between the two samplers was less than 50 meters. The sampling instrumentation at Lindon was installed at the current Lindon (LN) monitoring site. The ATEC sampler at Lindon was also sampling through stainless steel tubing and a single-port glass manifold attached to a blower inside the shelter. The PM_{10} sampler was installed on the roof of the same shelter.

Both Lindon and West Valley toxics samplers operated in the low-flow mode for carbonyl sampling with a rate of 0.50 liters per minute at standard temperature and pressure. Toxic VOCs were collected in evacuated, trace-level certified electropolished (SUMMA) stainless steel canisters. Carbonyl and PM_{10} blanks were collected every tenth sample.

The Bountiful station operated on a 1-in-6 day schedule staggered with the EPA's regular 1-in-6 day pattern to achieve the resulting 1-in-3 day frequency. A proprietary TRI Inc. sampler, which is standard

NATTS equipment, was used for carbonyl and VOC sampling. A manual Partisol 2000 sampler, also a part of NATTS, was used for PM_{10} collection.

DAQ contracted Atmospheric Analysis & Consulting, Inc. (AA&C) to perform TO-11a (carbonyl) and TO-15 (VOC) analyses. Table 1 shows the analytes reported by these methods. Utah State Health Laboratories performed ion chromatography analyses to determine the levels of manganese, arsenic,

Table 1. A list of TO11-a and TO-15 analytes provided by AA&C.

TO-15

Chlorodifluoromethane	1,2-Dichloropropane
Propene	Bromodichloromethane
Dichlorodifluoromethane	1,4-Dioxane
Chloromethane	Trichloroethene (TCE)
Dichlorotetrafluoroethane	2,2,4-Trimethylpentane
Vinyl Chloride	Methyl Methacrylate
1,3-Butadiene	Heptane
Bromomethane	cis-1,3-Dichloropropene
Chloroethane	4-Methyl-2-pentanone (MiBK)
Dichlorofluoromethane	trans-1,3-Dichloropropene
Ethanol	1,1,2-Trichloroethane
Vinyl Bromide	Toluene
Trichlorofluoromethane	2-Hexanone (MBK)
2-Propanol (IPA)	Dibromochloromethane
Acrylonitrile	1,2-Dibromoethane
1,1-Dichloroethene	Tetrachloroethene (PCE)
Methylene Chloride (DCM)	Chlorobenzene
Tert Butanol (TBA)	Ethylbenzene
Allyl Chloride	m & p-Xylenes
Carbon Disulfide	Bromoform
Trichlorotrifluoroethane	Styrene
trans-1,2-Dichloroethene	1,1,2,2-Tetrachloroethane
1,1-Dichloroethane	o-Xylene
Methyl Tert Butyl Ether (MTBE)	Isopropylbenzene (Cumene)
Vinyl Acetate	2-Chlorotoluene
cis-1,2-Dichloroethene	4-Ethyltoluene
Hexane	1,3,5-Trimethylbenzene
Chloroform	1,2,4-Trimethylbenzene
Ethyl Acetate	Benzyl Chloride (a-Chlorotoluene)
Tetrahydrofuran	1,3-Dichlorobenzene
1,2-Dichloroethane	1,4-Dichlorobenzene
1,1,1-Trichloroethane	1,2-Dichlorobenzene
Benzene	1,2,4-Trichlorobenzene
Carbon Tetrachloride	Naphthalene
Cyclohexane	Hexachlorobutadiene

TO-11a

Formaldehyde	Methacrolein
Acetaldehyde	MEK & Butyraldehyde
Acrolein	Benzaldehyde
Acetone	Valeraldehyde
Propionaldehyde	m-Tolualdehyde
Crotonaldehyde	Hexaldehyde

cadmium, and lead, which are the four metals that were found at health-relevant concentrations in the

previous study[1]. Chromium (VI) was not analyzed as it required a separate sampling and analytical methods beyond of the budget of this study.

The analysis included determining whether statistically significant differences in the observed concentrations existed between weekdays (Monday through Friday), weekends (Saturday and Sunday), and summer (May through August) and winter (November 15 through February) seasons using a student's t-test at the 95% confidence level. If the distribution of the concentrations at each location was not normal, it was normalized by log-transformation prior to performing the student's t-test. The analysis also considered correlations with heat deficit (a measure of the intensity of an inversion), temperature, and wind speed. Variables were considered correlated when coefficients of determination (R^2 values) were greater than 0.6; weakly correlated when R^2 was in the range of 0.3 to 0.6, and uncorrelated when R^2 was below 0.3.

Pollution and wind roses can be found in the supplementary materials section for each location, including the study average, the average for each location in the summer and winter, and the average for selected days when HAP concentrations significantly exceeded a cancer risk of one-in-one million.

Health Risk Metrics

Two health screening metrics are used in this report. Both of these metrics assume a life-long exposure to a pollutant concentration in the ambient air. The one-in-one-million cancer risk threshold is the more stringent of the two and is represented by a solid red line in the charts throughout this document. It is labeled "canc." in the figures included in this document. The EPA National Air Toxics Network documentation states:

> A risk level of "N"-in-1 million implies a likelihood that up to "N" people, out of one million equally exposed people would contract cancer if exposed continuously (24 hours per day) to the specific concentration over 70 years (an assumed lifetime). This would be in addition to those cancer cases that would normally occur in an unexposed population of one million people. Note that this assessment looks at *lifetime* cancer risks, which should not be confused with or compared to *annual* cancer risk estimates. If you would like to compare an annual cancer risk estimate with the results in this assessment, you would need to multiply that annual estimate by a factor of 70 or alternatively divide the lifetime risk by a factor of 70.[2]

The second, and less stringent, metric used is the non-cancer risk threshold represented in the charts by a dashed orange line. The EPA documentation states:

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[1] http://www.deq.utah.gov/ProgramsServices/programs/air/research/projects/toxicsmonitoring/docs/2016/02Feb/ToxicsOverviewReview.pdf

[2] https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms

> The risk associated with effects other than cancer, based on the reference concentration, which is an estimate, with uncertainty spanning perhaps an order of magnitude, of an inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risks of deleterious effects during a lifetime. [3]

The non-cancer risk threshold concentration is labeled “non-c.” in the figures included in this document.

[3] https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms

Volatile Organic Compounds

Formaldehyde

Formaldehyde is mainly used as an intermediate in chemical synthesis as well as in manufacturing of resins used in particle board. It is also used in various fumigants, cosmetics, and as an additive in construction materials.[4] Formaldehyde is also a common byproduct of power plants, incinerators, motor vehicle exhaust, and oil refining.[5] As a by-product of the atmospheric degradation of most organic compounds, large quantities of formaldehyde are formed in the atmosphere through secondary chemistry. Once in the atmosphere, it is an important OH precursor. Its photo-reactive nature affords formaldehyde a short lifetime on warm, sunny days and makes it an important contributor to the photochemical ozone formation.

Prolonged exposure to formaldehyde has been associated with some types of nasal and lung cancers. It is currently classified by the EPA as Group B1, a probable human carcinogen. Ordinary exposure levels for formaldehyde range between 0.3 – 3 parts per billion (ppb) for indoor and 10 – 20 ppb for urban areas.[6] Figure 1 shows the formaldehyde values at the three sampling sites throughout the study. A stark difference in day-to-day formaldehyde values is observed between Bountiful and the other two sites. Especially pronounced are the peak values that occurred between April and July, reaching concentrations up to 20 ppb.

The boxplots of formaldehyde shown in Figure 2 display a characteristic seasonal pattern in formaldehyde values across two of the three sites. Summer levels of formaldehyde tend to be higher on average than the winter values, which are expected due to increased photochemical activity in the summer months. Median summer formaldehyde concentrations observed at Lindon and West Valley were higher than in the winter. However, the summer formaldehyde values observed in Bountiful were lower than in the winter.

Comparing the study-long medians indicates that the higher concentrations are observed at the Bountiful site. However, the formaldehyde median concentrations were similar between the three sites during warm summer months. Such similarity across the three sampling location is likely due to the activation of biogenic sources of formaldehyde that overwhelm the anthropogenic sources that are more pronounced in the colder months, as well as improved mixing and enhanced removal mechanisms. The elevated annual formaldehyde median at Bountiful was driven by the consistently elevated wintertime measurements.

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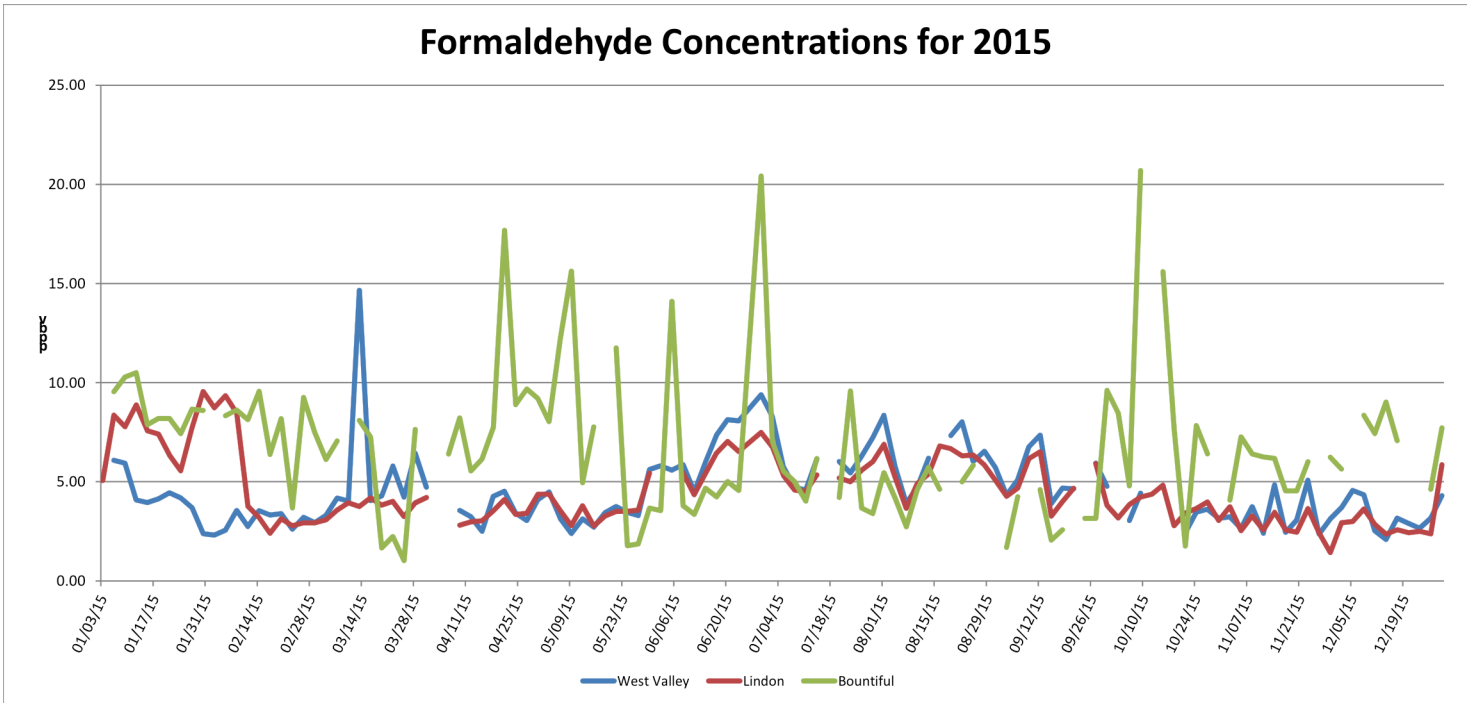
[4] Formaldehyde Hazard Summary, EPA, 2000 (https://www3.epa.gov/airtoxics/hlthef/formalde.html)

[5] Final Report on the Identification of Formaldehyde as a Toxic Air Contaminant, California ARB, 1992 (http://oehha.ca.gov/air/toxic_contaminants/html/Formaldehyde.htm)

6 Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Formaldehyde (Draft). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1997.

It is important to note that even though the boxplots for winter formaldehyde in West Valley and Lindon seem different the difference only lies in the spread of the values. The variance in formaldehyde concentrations in Lindon was greater than that of West Valley during the winter months even though the medians were essentially identical. Several factors may influence the significant difference in formaldehyde values between Bountiful and the other two sites. Some of these influences could be

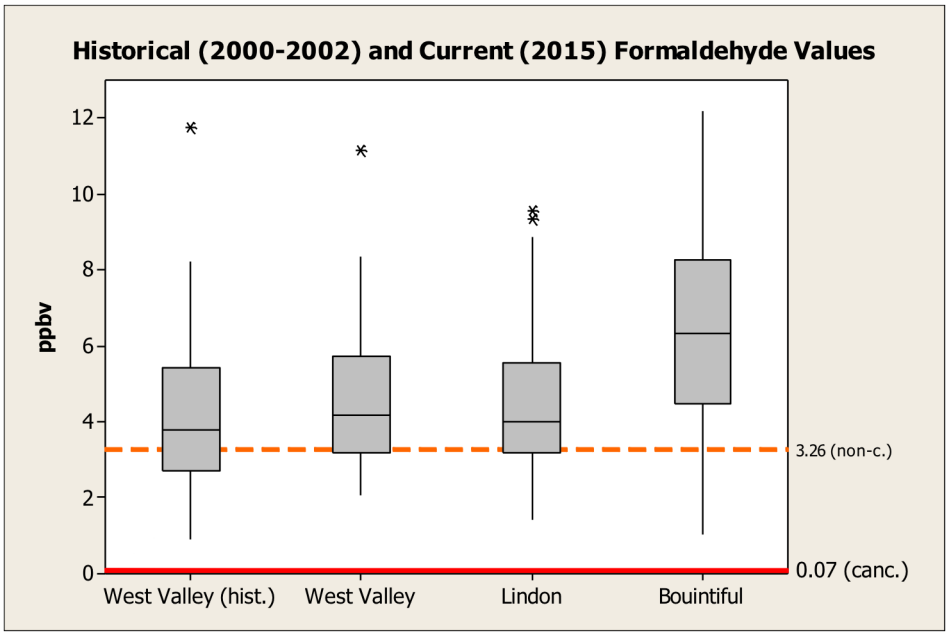
Figure 1. Formaldehyde concentrations observed at the West Valley, Lindon, and Bountiful during 2015.

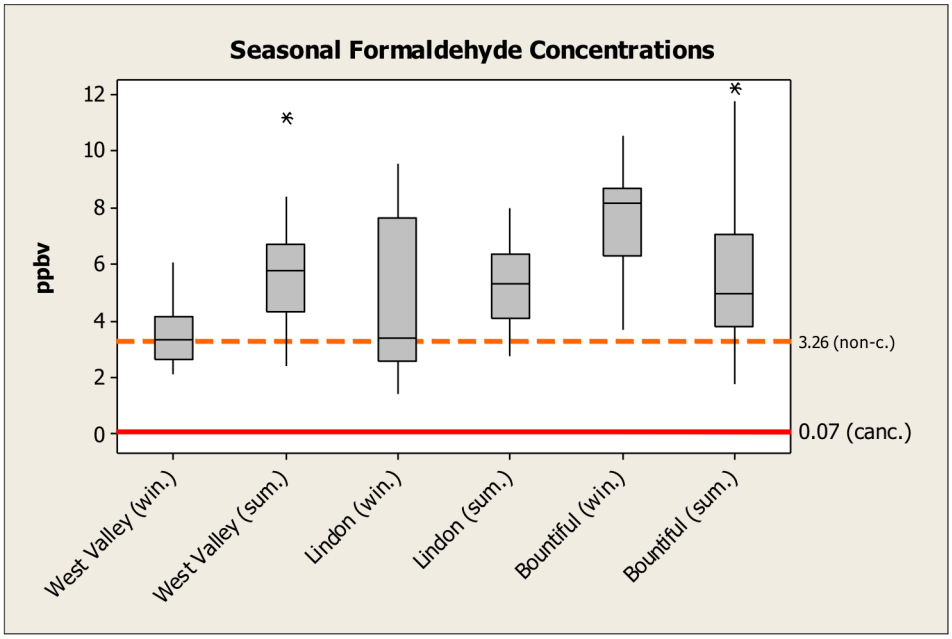


proximity to primary emitters of formaldehyde or the emitters of precursor VOCs which react to create formaldehyde, topographical enhancement the pollutant levels, and the influence of the Great Salt Lake and Utah Lake. The lakes may play a role because the reflectivity of the lake surfaces may enhance formaldehyde-forming photochemistry by increasing albedo in the winter.

As mentioned earlier, there was no significant difference between the formaldehyde medians and variance observed at the three locations during summer. This indicates that the impact of any anthropogenic source, combined with the possible lake effect, is overwhelmed by increased mixing and movement of the air mass as well as enhanced photochemistry driving removal of the pollutant. Formaldehyde lifetime in the summer is on the order of 6 to 10 hours, enough for an effective dispersion across the valley. This lifetime may increase significantly in the winter due to lower

Figure 2. Formaldehyde concentrations observed at West Valley, Lindon, and Bountiful during 2015. Seasonal and historic data are included.





temperatures and low photochemical activity. Additionally, a stable mixing layer coupled with low wind speeds, and therefore poor transport, could drive local formaldehyde concentrations. Thus, the presence of primary formaldehyde emission sources in Bountiful could account for the unusually high values observed there.

Heat deficit, a way to measure the strength of wintertime inversions, did not correlate with formaldehyde values. Formaldehyde concentration exhibited a slight positive correlation with temperature in Lindon, but not at the other two locations. No significant differences between formaldehyde concentrations on weekends and weekdays were observed.

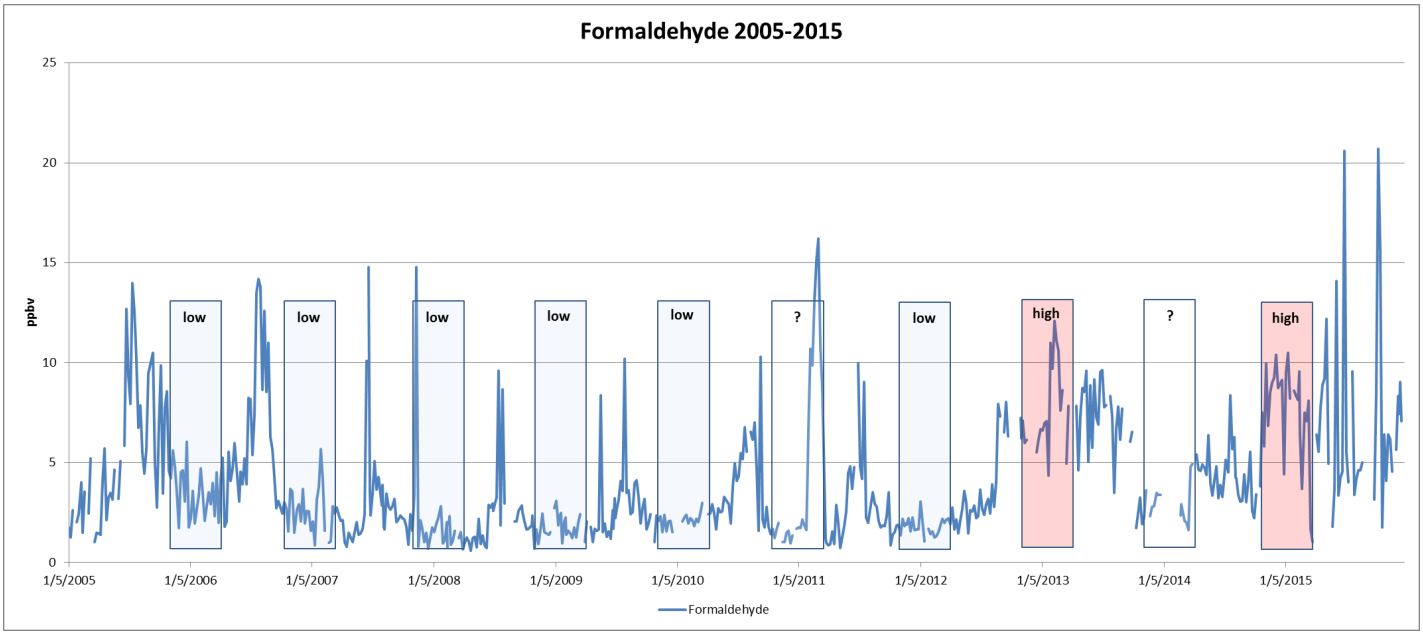
As a part of the investigation process, wind speed and wind direction were analyzed for the high-formaldehyde events. A high correlation with any particular wind direction and a negative correlation with the wind speed would suggest a nearby primary emission source. No correlation was found for wind speed and direction and formaldehyde concentration. Pollution roses for the high-formaldehyde events were inconclusive and did not point in any distinct direction (see supplementary materials section for the detailed graphs).

It is interesting to note that formaldehyde and acetaldehyde concentrations have R^2 values of 0.79 in West Valley, 0.7 in Lindon, 0.81 in Bountiful. As acetaldehyde could serve as a source for secondary formation of formaldehyde, it is possible that whatever the source of formaldehyde is, it also emits acetaldehyde. Alternatively, the source could emit a precursor for both of the pollutants simultaneously, driving the elevated concentrations for both pollutants

The long-term historical trend, displayed in Figure 3, shows formaldehyde observations in Bountiful between 2005 and 2010. Only two seasons, winter of 2012-2013 and 2014-2015, displayed formaldehyde values similar to the ones observed in this study. December 2015 had elevated concentrations of formaldehyde suggesting that the pattern was likely persisted during the winter of 2015-2016.

Formaldehyde concentrations tended to stay low for the rest of the seasons, generally below 5 parts per billion by volume (ppbv), with the exception of an unusual spike in February and March of 2011. The formaldehyde trend for the winter of 2013-2014 was not clear because of the failure of sampling equipment for that season.

Figure 3. Long-term formaldehyde observations in Bountiful.



The data from the figure suggests that the annual formaldehyde trend followed the typical pattern of high-in-the-summer/low-in-the-winter until the winter of 2013. The increase in wintertime formaldehyde concentrations observed since 2013 is statistically significant and natural variations in formaldehyde data could not account for the elevated concentrations observed in the last three years.

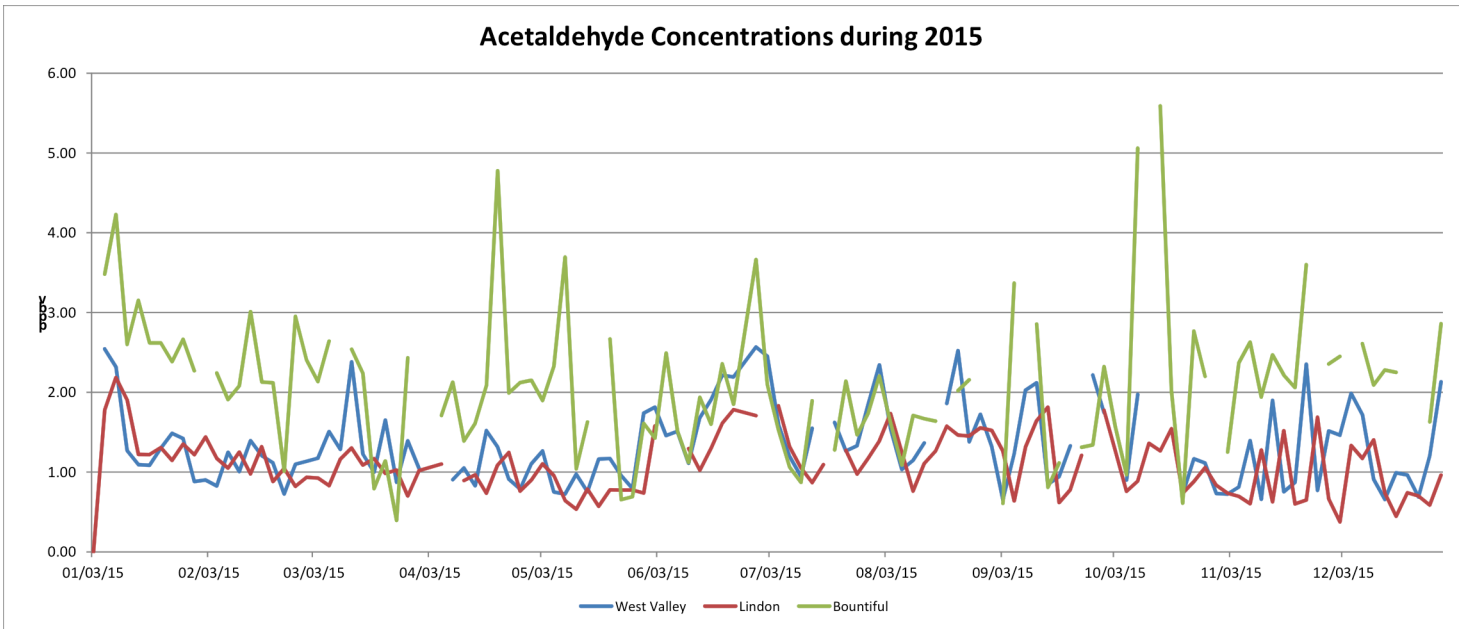
Acetaldehyde

Acetaldehyde is one of the major participants in atmospheric chemical processes. It is released into the environment through incomplete wood combustion, vehicle exhaust, and waste processing. It is also released during plant respiration and is one of the intermediates in the photochemical oxidation of volatile organic compounds. Tobacco smoke is one of the major pathways for individual exposure to both formaldehyde and acetaldehyde.[7]

Short-term exposure to acetaldehyde causes irritation of the eyes, skin, and respiratory tract. Long-term exposure to acetaldehyde causes olfactory degeneration in rats and hamsters. As of yet, studies haven't demonstrated conclusive results regarding the health effects of acetaldehyde on people. It is classified as a probable human carcinogen based on the insufficient number of human exposure studies.

Figure 4 shows the concentrations of acetaldehyde throughout the study at the three sampling sites. It is clear that acetaldehyde values tended to be higher at the Bountiful site compared to the other two sites.

Figure 4. Acetaldehyde concentrations observed at West Valley, Lindon, and Bountiful in 2015.



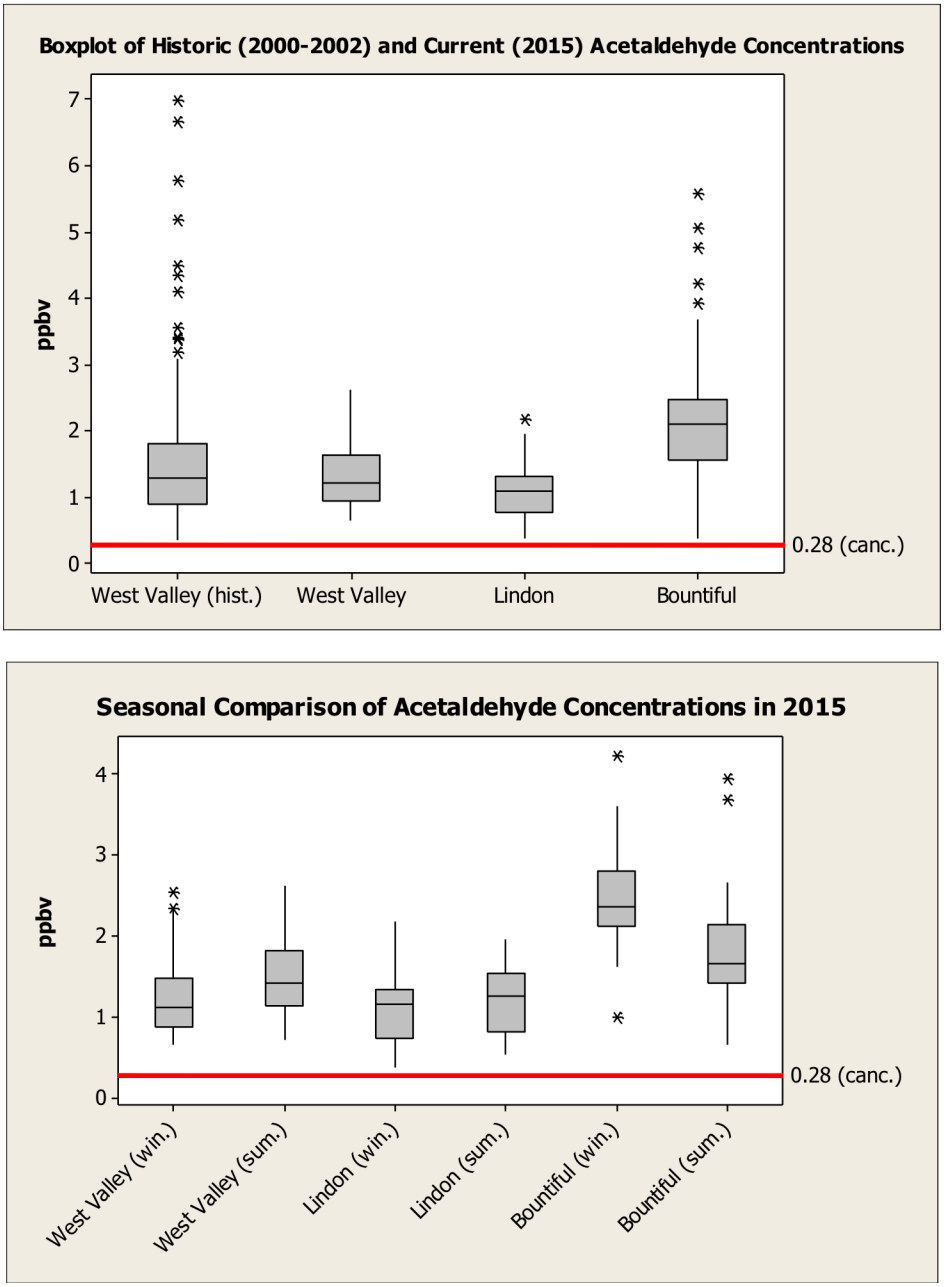
In general, acetaldehyde follows the same general trend as formaldehyde, with higher concentrations in the summer enhanced by biogenic emissions and more active photochemistry. This trend holds true for

[7] U.S. Environmental Protection Agency. Health Assessment Document for Acetaldehyde. EPA/600/8-86-015A. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Research Triangle Park, NC. 1987.

the West Valley and Lindon sites as observed in the boxplot graphs in Figure 5, but was reversed at the Bountiful site, with the wintertime median concentration above that detected in the summer. This is the same spatial and seasonal trend as was observed with formaldehyde.

The boxplots also show that the greatest concentrations and variance of acetaldehyde was observed in Bountiful throughout the study. Additionally, acetaldehyde was observed at higher concentrations at Bountiful in each season. The West Valley site had the second highest median acetaldehyde concentration, followed closely by Lindon. Historic acetaldehyde values observed in West Valley were comparable to those obtained during this study.

Figure 5. Data summary for acetaldehyde observed in 2015 for all three sampling locations. Historical and seasonal values included.



Acetaldehyde concentrations did not correlate with heat deficit or with temperature. No significant difference between formaldehyde concentrations on weekends and weekdays was observed. As a part of the investigation process, wind speed and wind direction were analyzed for the high-acetaldehyde events. No correlation was found between wind speed and acetaldehyde concentration.

Because of low levels of activity, it is unlikely that the biogenic sources are significant contributors to the high acetaldehyde values in Bountiful during winter. The observed concentrations are likely caused by

either primary emission sources or sources that emit acetaldehyde precursors. Wind roses for the high acetaldehyde days indicate that the predominant wind direction was east-by-southeast (see supplementary materials section for the detailed graphs). However, this wind direction is well aligned with the common diurnal wind pattern for the area.

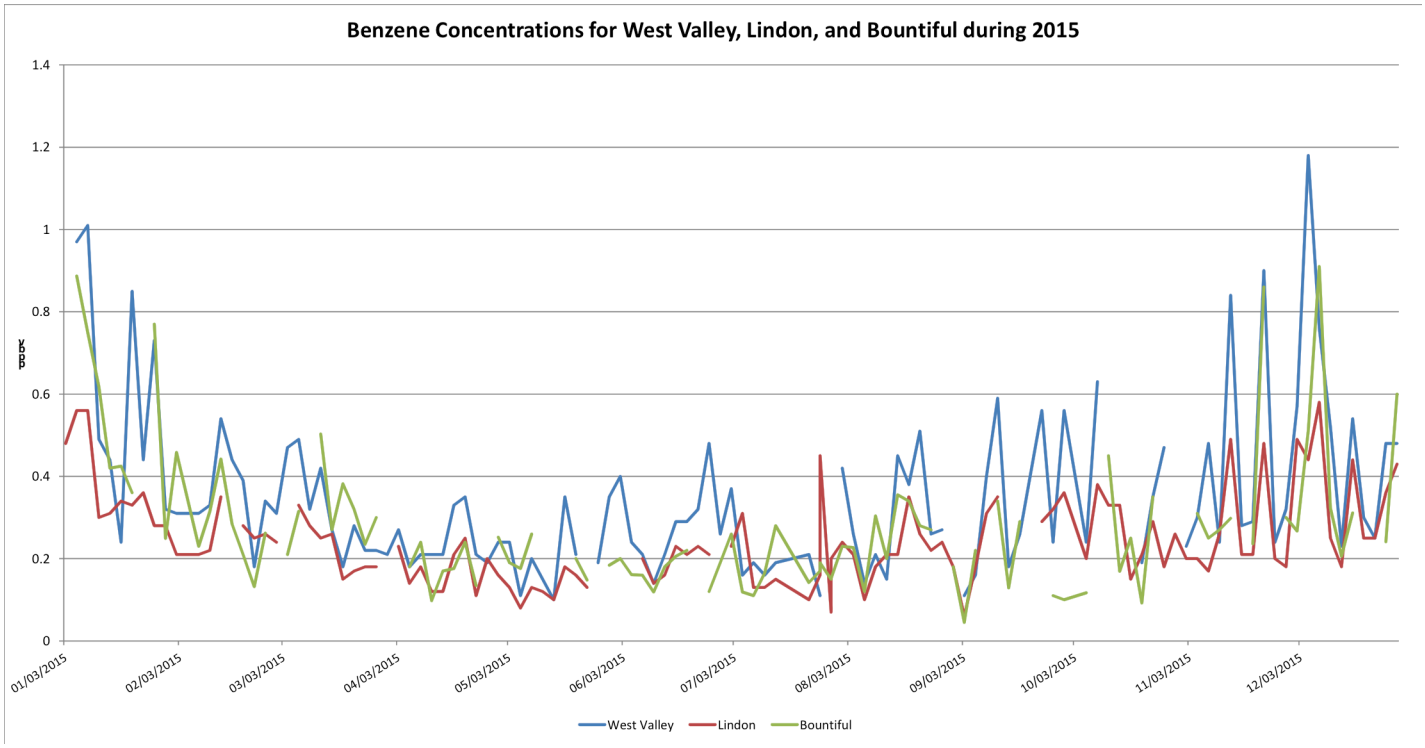
It is interesting to note that R^2 values for formaldehyde and acetaldehyde were 0.79, 0.7, 0.81 in West Valley, Lindon, and Bountiful, respectively. As acetaldehyde could serve as a secondary source of formaldehyde, it is possible that whatever the source of formaldehyde is, it also emits acetaldehyde. Alternatively, the source could emit a precursor for both of the pollutants simultaneously, driving the elevated concentrations for both.

Benzene

Barring benzene manufacturing facilities, the primary sources of ambient benzene are motor vehicles, coal burning, gasoline, oil, and evaporation at automobile service stations.[8,9] Chronic inhalation exposure has caused various disorders in the blood in occupational settings. These disorders include reduced red blood cell counts and aplastic anemia. Adverse reproductive effects have been reported in women exposed to high levels of benzene. Adverse effects on developing fetuses have been observed in animal tests. Increased incidences of leukemia (cancer of the tissues that form white blood cells) have been observed in humans occupationally exposed to benzene. The EPA has classified benzene as a known human carcinogen for all routes of exposure.

Figure 6 shows the benzene concentrations for the three sampling sites throughout the year. As with most organic compounds, higher average concentrations of benzene are observed during the colder months of the year. This typical trend presents itself for numerous volatile organics because of the decreased rate of removal through photochemistry, a shallow boundary layer in winter, decreased solar radiation, and temperatures that are responsible for less efficient photochemistry in winter months.

Figure 6. Benzene concentrations for West Valley, Lindon, and Bountiful during 2015.

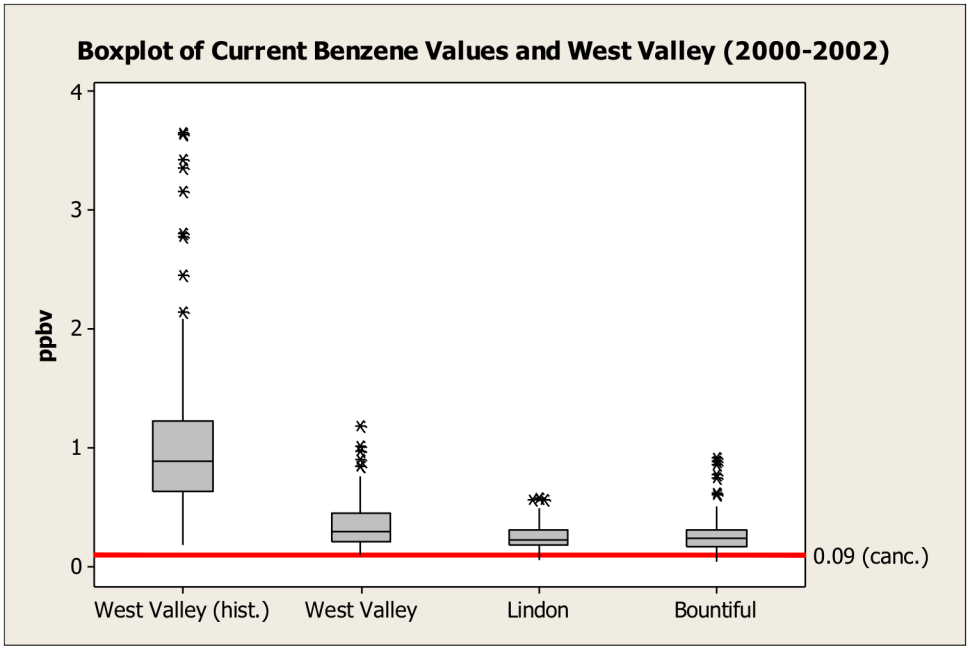


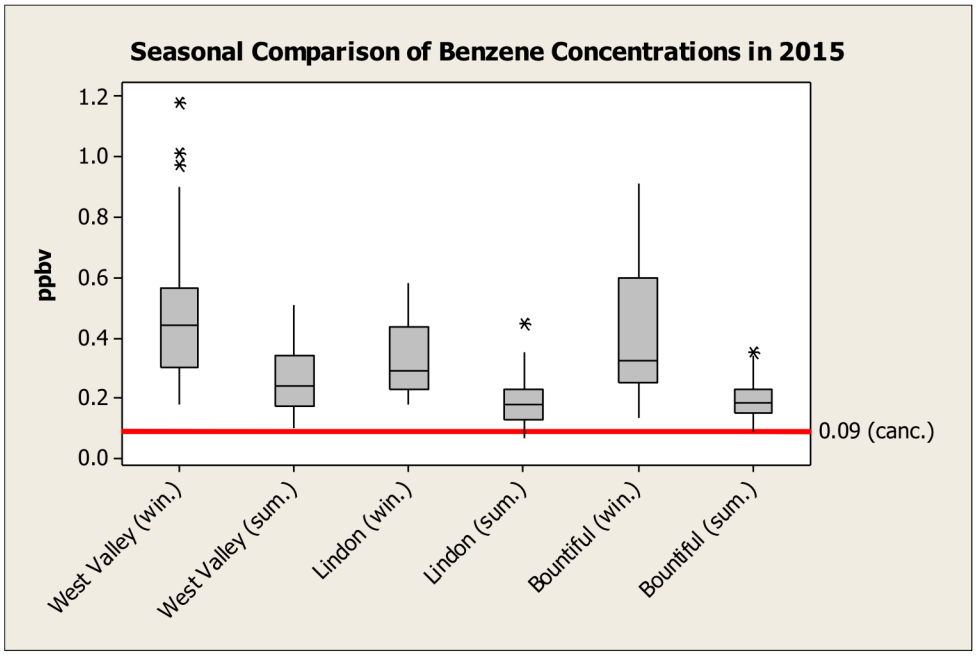
[8] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Benzene. U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 2007.

[9] M. Sittig. Handbook of Toxic and Hazardous Chemicals and Carcinogens. 2nd ed. Noyes Publications, Park Ridge, NJ. 1985.

Figure 7 is the summary of the benzene data acquired in the study, showing boxplots for the entire study and divided into summer and winter seasons.

Figure 7. Data summary for benzene. Includes seasonal data for West Valley, Lindon, and Bountiful, as well as historical West Valley data.





As in previous figures, the red line represents the one-in-one-million cancer risk threshold. The boxplots show that benzene values tended to be higher at West Valley, followed by Bountiful and

Lindon, respectively. The median difference between the benzene values among the three sites was greater in the summer, even though the ambient concentrations were lower than those observed in the winter.

The relatively elevated benzene values at West Valley point toward a greater presence of primary benzene sources. It is likely that these primary sources are dominated by automobiles and other machinery and processes that use internal combustion engines.

Benzene concentrations did not correlate with wind speed in any of the locations, but there was a slight negative correlation between temperature and wind speed at the Lindon site. No significant differences between concentrations on weekends and weekdays were observed. The pollution and wind roses can be found in supplementary materials section. The high-concentration benzene days tended to be associated with winds from the southeast or northwest in West Valley, winds from the west or east in Lindon, and no observable pattern in Bountiful. Further investigation would be necessary to associate benzene concentrations with a wind direction.

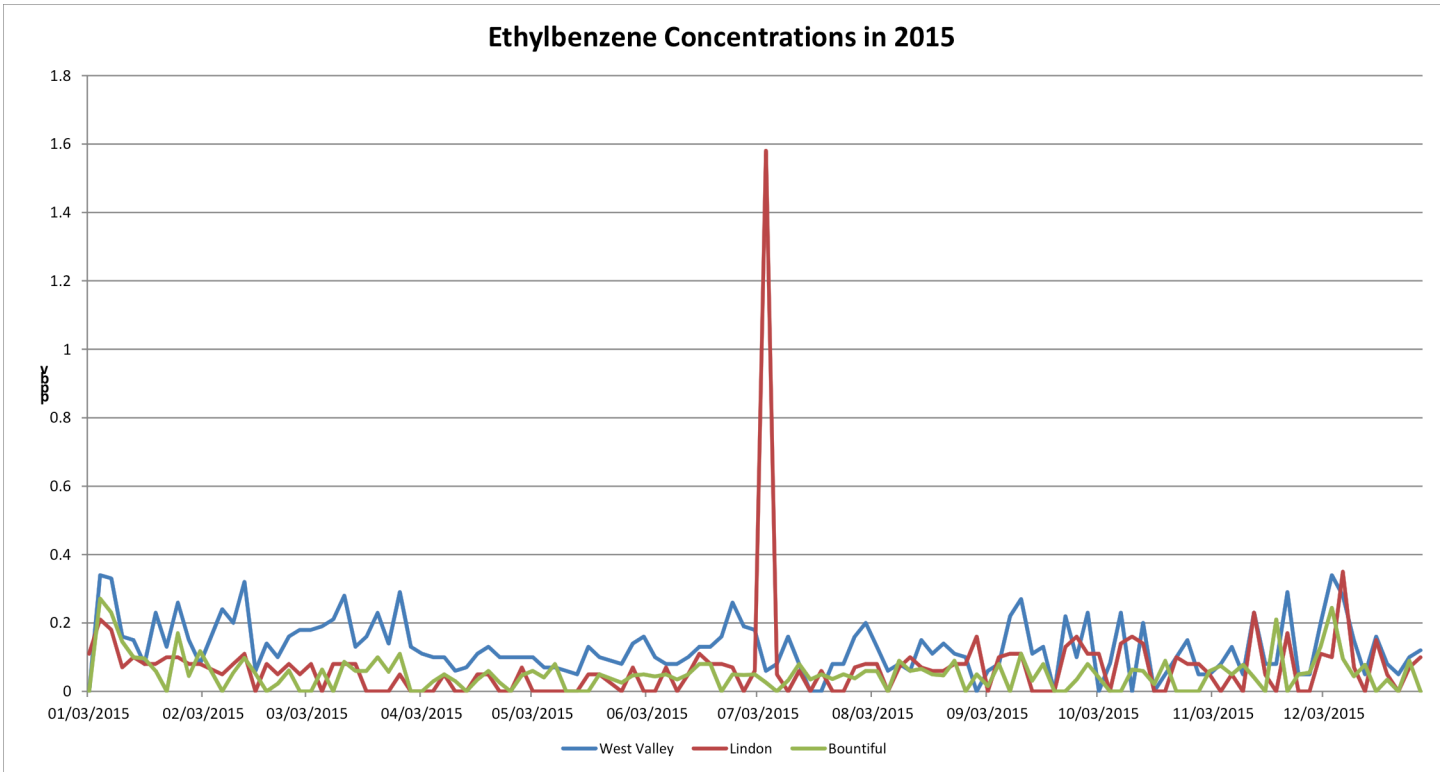
Comparing the current benzene values to those observed at the original West Valley toxics site between 2000 and 2002, a significant downward trend is observed. Nearly 100% of the current benzene measurements fall below the median of the old dataset, and more than 75% of the current data spans the first quartile of the historic values. This represents a drastic improvement in benzene exposure around the West Valley site in the last fifteen years. This downward trend follows the nationwide trend for benzene. National ambient benzene concentrations decreased by 66% between 1994 and 2009.

Ethylbenzene

Ethylbenzene is primarily used as a solvent and in styrene production. It is also a constituent of asphalt and is found in some fuels. Acute exposure to ethylbenzene leads to irritation of the eyes and throat, chest constriction, and dizziness. Chronic exposure to ethylbenzene has inconclusive effects on human health, but animal studies have shown detrimental effects on the kidneys, liver, and blood composition of test subjects. Currently, ethylbenzene is classified as a Group D pollutant; it is unclassifiable with respect to human carcinogenicity.[10,11]

Figure 8 shows the concentrations of ethylbenzene that were observed throughout the 2015 study. Aside from the unusually high spike observed on July 5th in Lindon, the concentrations of ethylbenzene tended to be mostly at or below the screening level for the contaminant (0.92 ppbv).

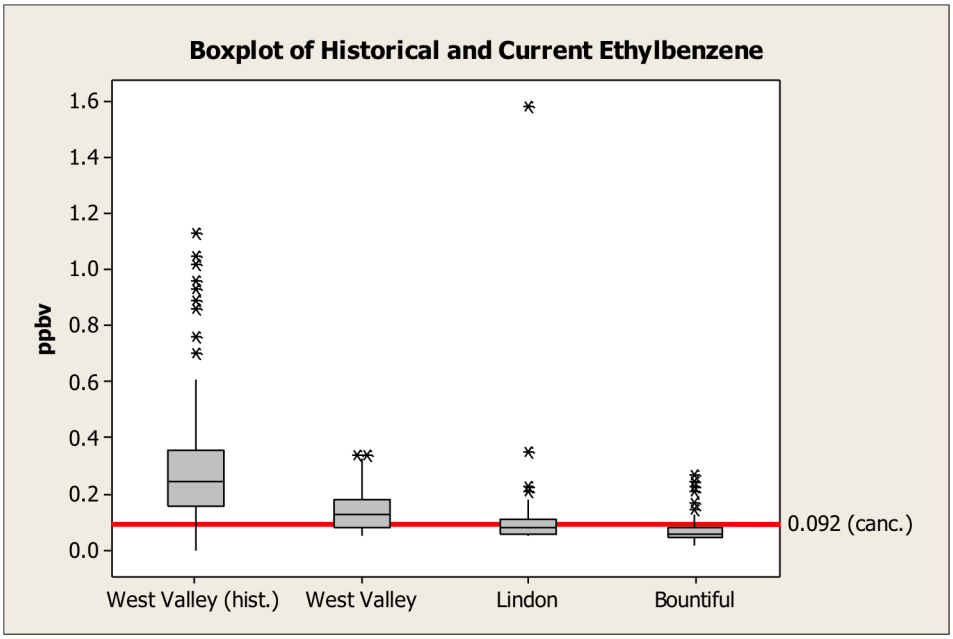
Figure 8. Ethylbenzene concentrations for West Valley, Lindon, and Bountiful during 2015.

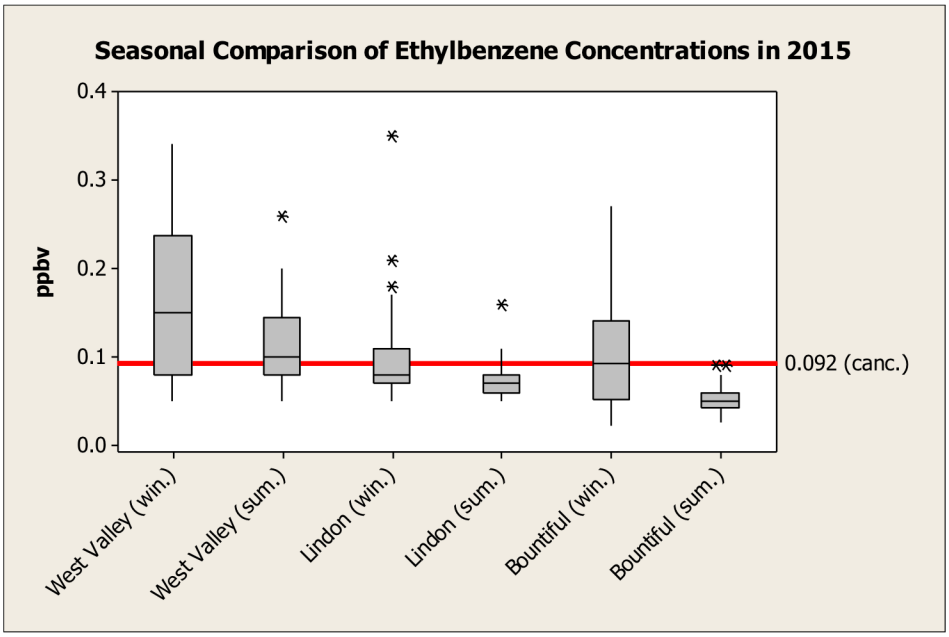


[10] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Ethylbenzene (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1999.

[11] E.J. Calabrese and E.M. Kenyon. Air Toxics and Risk Assessment. Lewis Publishers, Chelsea, MI. 1991.

Figure 9. Ethylbenzene summary for West Valley, Lindon, and Bountiful for 2015. Historical West Valley data is included. Summer and winter seasonal summaries for the three sites are presented.





As with most organic compounds, the seasonal variation of ethylbenzene follows the 'high in the winter – low in the summer' trend. Between the two seasons and throughout the study, ethylbenzene values were higher at the West Valley site than at Lindon or Bountiful. This difference was statistically significant at the Lindon site, but not at the two other sites.

Figure 9 shows that the ethylbenezene median value in West Valley was consistently above those observed in Lindon or Bountiful. Nearly 75% of ethylbenzene measurements at West Valley were above the one-in-one-million cancer risk threshold in the winter. Only 50% or less of the data was above that threshold at Lindon and Bountiful. Summer ethylbenzene values for Lindon and Bountiful were largely below the cancer risk threshold, while over one half of measurements in West Valley were above it.

Ethylbenzene concentrations did not correlate with temperature or wind speed in any of the locations, and no significant difference between concentrations on weekends and weekdays was observed. The pollution and wind roses can be found in supplementary materials section. For the high ethylbenzene-concentration days, Bountiful and West Valley showed no consistent pattern, and Lindon showed winds from the east southeast or west.

The historic ethylbenzene measurements obtained in West Valley show a significant decrease in current ethylbenzene emissions, where nearly 75% of the current measurements fall within the first quartile of those obtained between 2000 and 2002.

Carbon Tetrachloride

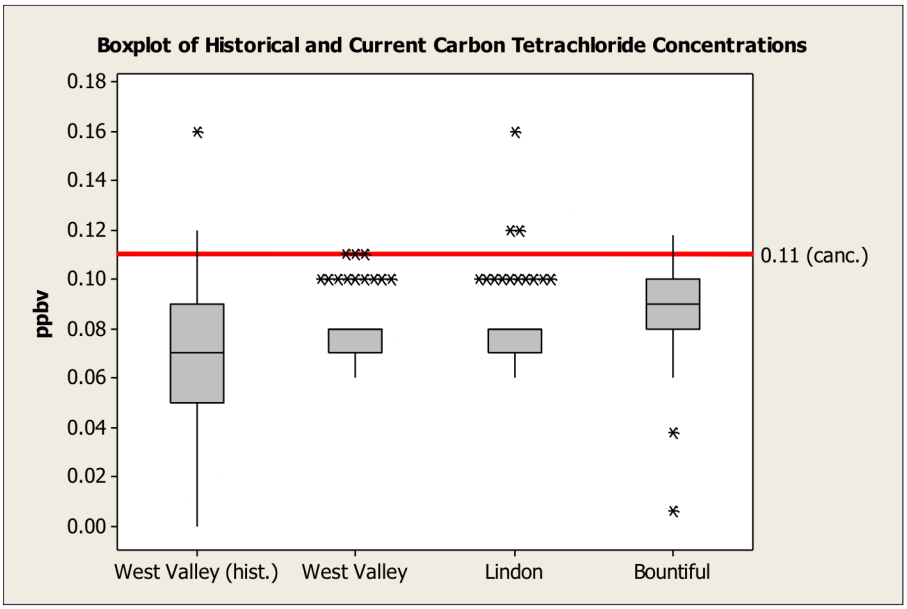
Carbon tetrachloride is a clear, colorless, highly volatile liquid. It presents itself with a characteristically sweet smell and because of its high volatility, human exposure mostly happens through inhalation. Its insolubility in water, inflammability, and a very low melting point proved extremely useful in many industrial and domestic applications. Prior to the amendment of Title VI of the Clean Air Act in 1990 that limited the emission and manufacturing of halogenated hydrocarbons, carbon tetrachloride was commonly used as an aerosol propellant, solvent, degreaser, and as a propellant for fire extinguishers. Currently, carbon tetrachloride is largely used in chemical synthesis processes and other applications where no suitable substitute has been found.[12]

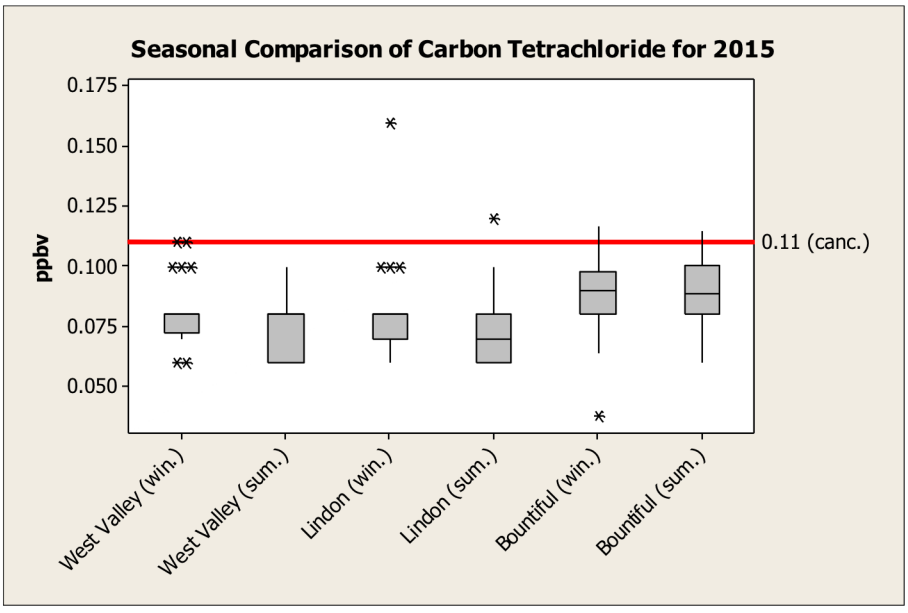
Typical background ambient concentrations of carbon tetrachloride are about 0.1 ppb. More polluted urban areas can experience slightly higher values. The concentrations of carbon tetrachloride were generally below the 0.11 ppb cancer risk threshold for all three sites throughout 2015. However, as shown in Figure 10, the carbon tetrachloride median concentration for the study was slightly higher at the Bountiful site (by approximately 13%). The same pattern was observed for each season between each of the sampling sites. However, no significant difference in the median concentration was observed from season to season at any of the three sites.

[12] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Carbon tetrachloride (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1994.

It is important to note that the vast majority of carbon tetrachloride samples yielded concentrations between 0.06 and 0.08 ppbv, values very close to the method detection limit. The reason for higher carbon tetrachloride values at the Bountiful site could be attributed to the proximity of an emission source.

Figure 10. Carbon tetrachloride data summary, including seasonal summaries, for West Valley, Lindon, and Bountiful sites for 2015.





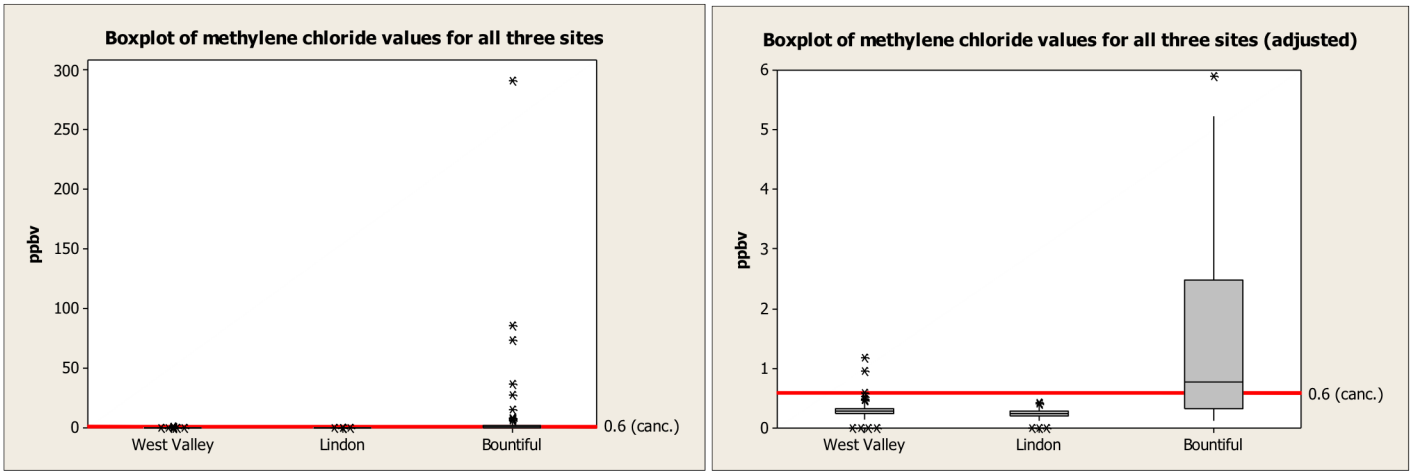
Carbon tetrachloride concentrations did not correlate with temperature or wind speed in any of the locations, and no significant difference between concentrations on weekends and weekdays was observed.

Methylene Chloride

Methylene chloride (dichloromethane) is substituted methane containing two chlorine atoms. It is not formed in the environment naturally and is released by a number of industrial and residential sources. The most common emission sources for methylene chloride are associated with its primary use as a solvent. It is used in paint strippers, manufacturing of drugs, and as a finishing solvent in electronics manufacturing. It also has uses as a propellant for various aerosols, polyurethane foams, and paints. Because of its high volatility the primary exposure route is by inhalation. It takes approximately 120 days for one half methylene chloride to decompose to carbon dioxide in the air.[13]

This study revealed significant levels of methylene chloride at the Bountiful sampling site throughout the year. Figure 11 shows methylene chloride boxplots for the three sites and the cancer-risk threshold. The variance in data at the Bountiful station was so great that the original plot had to be adjusted by scaling the vertical axis.

Figure 11. Data summary for methylene chloride during 2015.



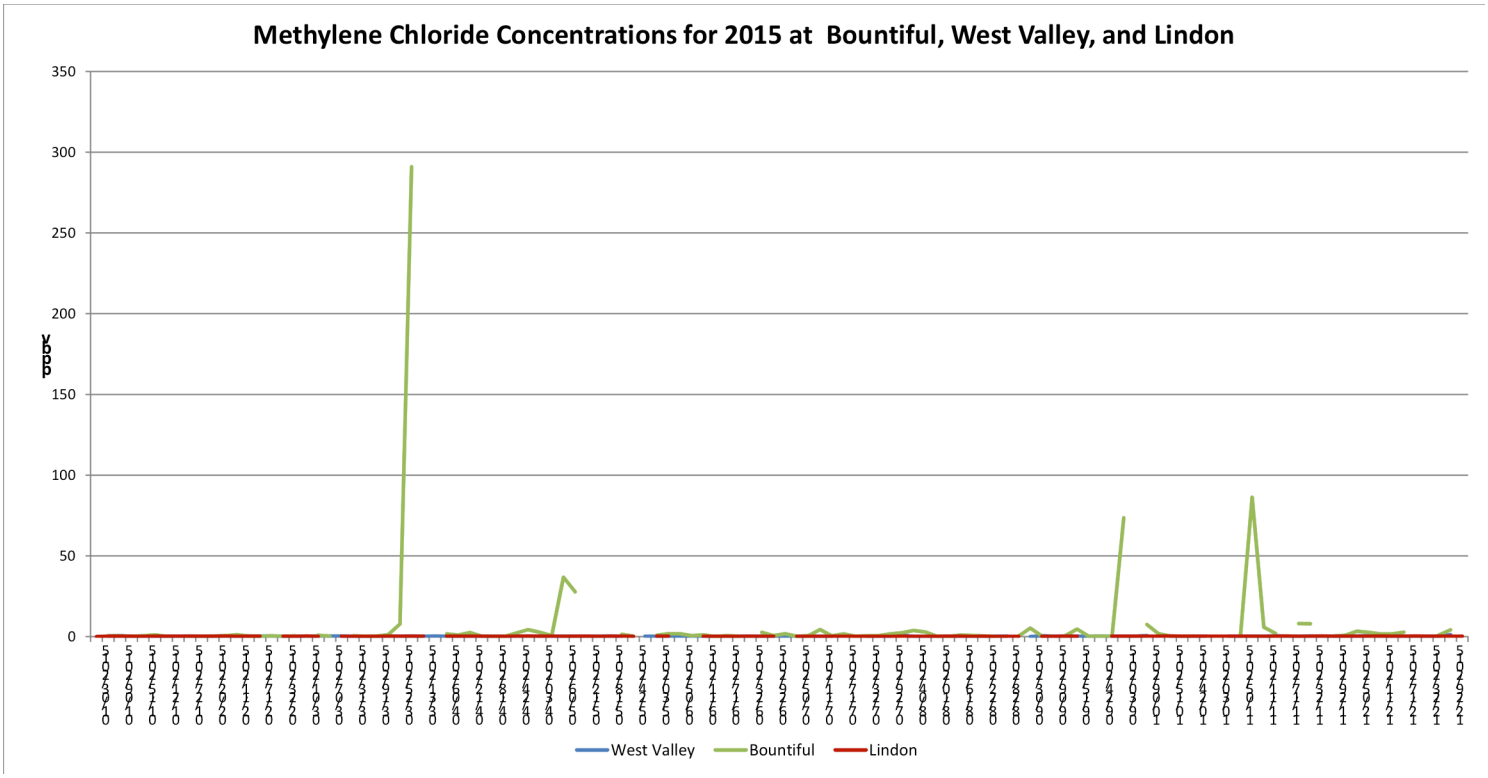
The figure shows that with the exception of two occasions, both West Valley and Lindon monitors recorded no observations above the cancer risk threshold for the compound. Bountiful, on the other hand, observed more than a half of its methylene chloride measurements above the cancer risk threshold. Additionally, there were at least seven events when the ambient methylene chloride concentrations were observed to be one to two orders of magnitude above the limit. On a single event

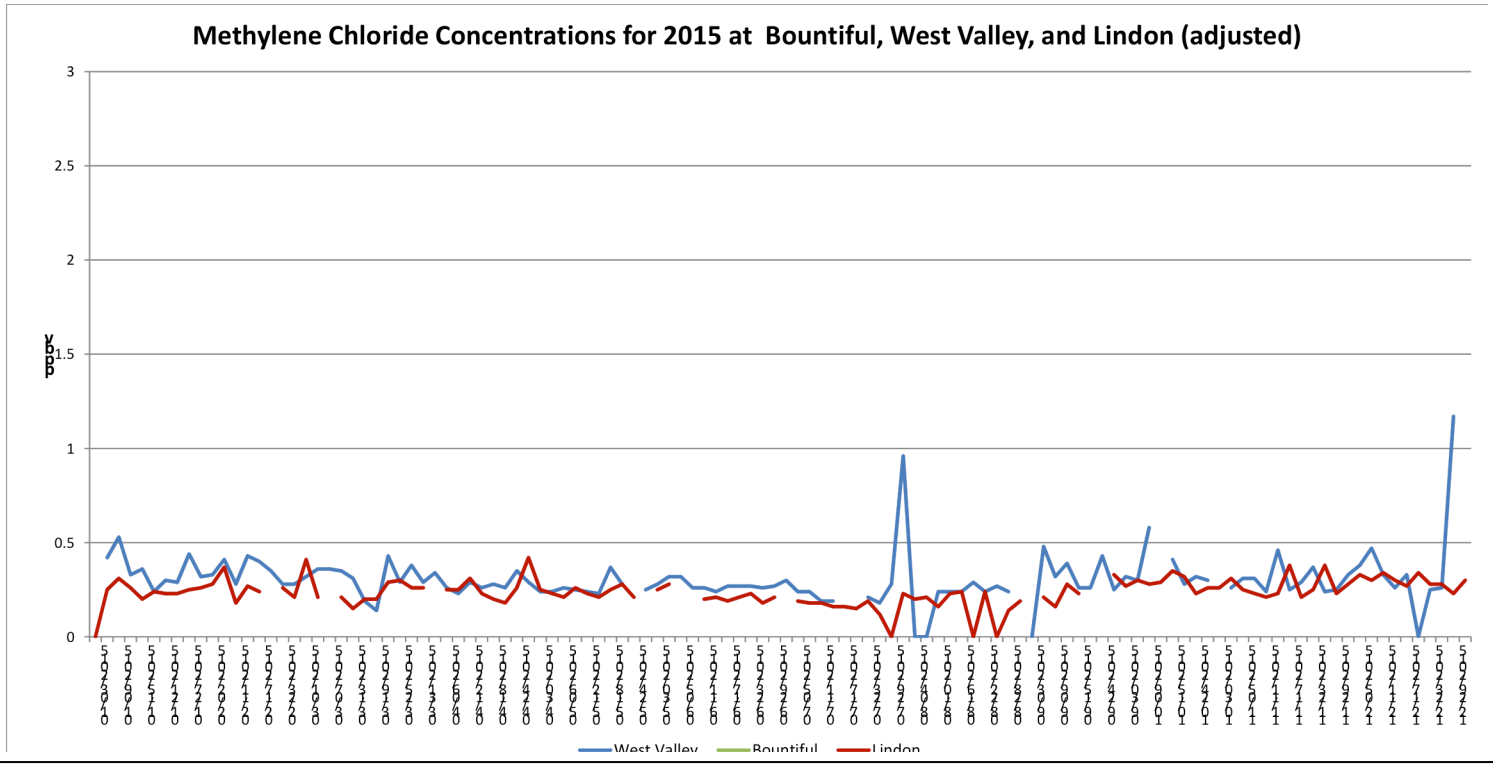
13 Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Methylene Chloride (Update).Draft for Public Comment. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1998.

of March 28, the Bountiful monitor observed the pollutant concentration of 291 ppbv, nearly 500 times above the cancer risk threshold and the ambient levels observed at the other two sites.

Figure 12 shows methylene chloride concentrations for the three sites throughout the study. As with the previous figure, the vertical scale on the upper chart in figure 2 had to be adjusted to make features at the West Valley and Lindon sites visible.

Figure 12. Methylene chloride concentrations for West Valley, Lindon, and Bountiful for 2015.



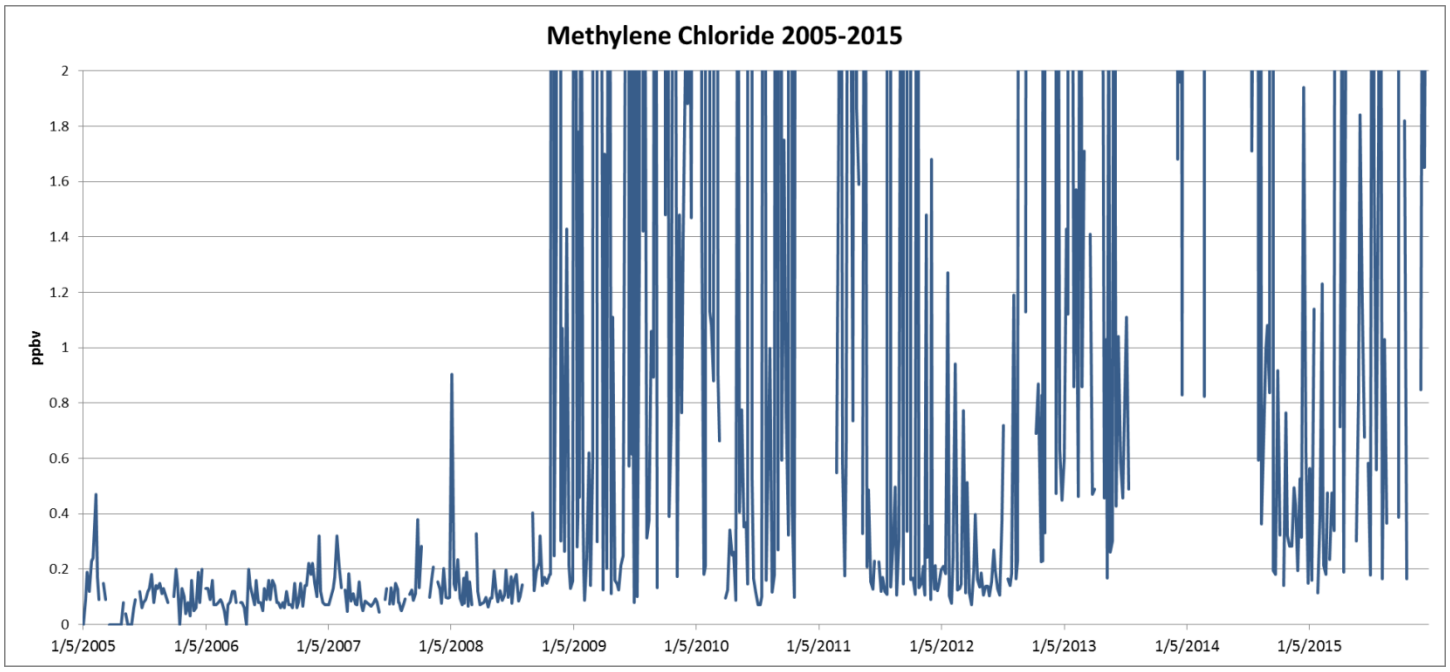


Methylene chloride exhibited no significant weekday/weekend, wind speed, or temperature trends. No statistically significant difference was observed between Lindon and West Valley methylene chloride concentrations. The concentrations at the Bountiful location were significantly higher in summer than in winter. However, there are three measurements with concentrations over 10 ppb, and if removed this difference is no longer significant.

The Bountiful site concentrations were on average higher than either West Valley or Lindon while the West Valley site concentrations were on average slightly higher than at Lindon. This might be related to methylene chloride dispersion behavior as it propagates from north to south across the valleys. However, it is more likely that the Bountiful and West Valley locations have more methylene chloride sources nearby than does Lindon. The methylene chloride concentrations at the three locations were uncorrelated with each other, which suggests that each site is affected by local sources.

Figure 13 shows methylene chloride measurements in Bountiful between 2005 and 2015. It is clear that a sudden increase in methylene chloride concentrations occurred and persisted since October 2008. Prior to 2008, methylene chloride concentrations were at the levels that were observed at Lindon and West Valley during this study. It is reasonable to assume that a strong methylene chloride source became active at the end of 2008. Weekend/weekday analysis yielded no correlation between work-days and the magnitude of methylene chloride emissions, suggesting that the source operates continuously.

Figure 13. Methylene chloride concentrations in Bountiful between 2005 and 2015.



A brief study from 2013 indicated that the predominant wind direction during the high methylene chloride events was from north-west; however the wind roses generated for the exceptional events in

2015 were not uniform. Although the March 28th high methylene concentration was associated with winds from the north-northwest, further investigation is required to identify the sources of this pollutant in Bountiful.

Other

1,4-Dichlorobenzene

1,4-Dicholorobenzene is primarily an indoor pollutant. It is mainly used as a fumigant against mold, mildew, and moths, as well as a deodorant for toilets. Sometimes, 1,4-dichlorobenzene is produced as an intermediate compound during the manufacturing of other chemicals.

As with most chlorinated organics, 1,4-dichlorobenzene attacks the kidneys, liver, and the central nervous system. Although there is little data from human carcinogenic studies, 1,4-dichlorobenzene is classified as a possible human carcinogen. Prolonged exposure of rats through inhalation caused changes in kidney and liver function, as well as blood. Direct exposure to the chemical in the animals' stomachs caused the formation of malignant tumors.[14]

1,4-Dichlorobenzene was not observed above the method detection limit (MDL) with any degree of consistency or frequency at any of the three sites. Only three measurements above the MDL were observed at the West Valley site; one at Lindon, and nine at Bountiful. All of these measurements were above the one-in-one-million cancer threshold risk of 0.015 ppb. The highest measurement of this pollutant was observed at Bountiful on October 15th at 0.17 ppb.

1,2-Dichloroethane

1,2-Dichloroethane (ethylene dichloride) is a hazardous chemical that has deleterious effects on human nervous, cardio, respiratory, and reproductive systems. Its cancer risk exposure levels have been modeled, but detailed studies of its carcinogenic effects are insufficient. As such, it is classified as a Group B2, probable human carcinogen. Ethylene dichloride is frequently used in chemical synthesis of other chlorinated compounds and a dispersant in plastics and rubber.[15]

1,2-Dichloroethane was not consistently detected above one-in-one-million cancer risk threshold of 0.098 ppb in West Valley or Lindon. Only 18 samples collected at the West Valley site were above MDL, and only a single sample was detected in Lindon. Nearly 55% of the 1,2-dichloroethane measurements in Bountiful were above the detection limit. However, all of those measurements were detected by the EPA's laboratory which had more sensitive analytical equipment. All of the Bountiful measurements were below 0.05 ppb, while only a single measurement in West Valley was above the cancer risk screening level.

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[14] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for 1,4-Dichlorobenzene (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1998.

[15] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for 1,2-Dichloroethane. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1992.

1,3-Butadiene

1,3-Butadiene is primarily released from motor vehicle exhaust, forest fires, plastic manufacturing facilities, and oil refineries. It is widely present in urbanized areas, and despite its short atmospheric lifetime, it may reach concentrations of 0.3 ppb. Acute exposure to 1,3-butadiene causes irritation of the eyes, lungs, and mucous membrane. Chronic exposure to this substance is associated with increased incidences of leukemia in humans and tumors in animals. 1,3-butadiene has been classified as a human carcinogen.[16]

The only station where 1,3-butadiene was consistently detected was Bountiful. Forty-four percent of the 1,3-butadiene detects were done by the NATTS program monitor. Only 17% and 3% of total samples detected 1,3-butadiene at the West Valley and Lindon sites, respectively. The Bountiful 1,3-butadiene concentrations remained within the historical range observed at that location since 2007. However, the concentrations observed in West Valley were all above the non-cancer exposure level of 0.09 ppb and slightly above those observed between 2000 and 2002. Considering that only 19 observations above MDL were made for the year, drawing conclusions about the trend this pollutant seems unreasonable.

Metals

Lead

Lead often appears in the environment as the result of industrial activities. It is commonly emitted during mining operations and smelting activities. Lead is also an additive in aircraft gasoline, but its use in automobiles has been phased out and banned. Some of the lead exposure in the environment occurs from disturbing ground near old roadways where lead was deposited as a result of the lead fuel additive prior to the phase out. Lead, as an additive to older paints, remains a health hazard in old buildings and residences.

Once introduced into the body, lead accumulates in the bones. Its exposure is characterized by harmful effects on the kidney, immune, nervous, and cardiovascular systems. Lead is also linked to diminished cognitive abilities, low IQ, and altered memory and behavior. Children and infants are most susceptible to the effects of lead exposure. No safe blood lead level in children has been identified.[17,18]

Data collection efficiency, the ratio of the sample detects to the number of attempted samples, for lead was very high throughout the study. Because of a sampler breakdown, 24% of the West Valley data were non-detects or missed samples, but only 7% of the samples collected at Lindon were in that

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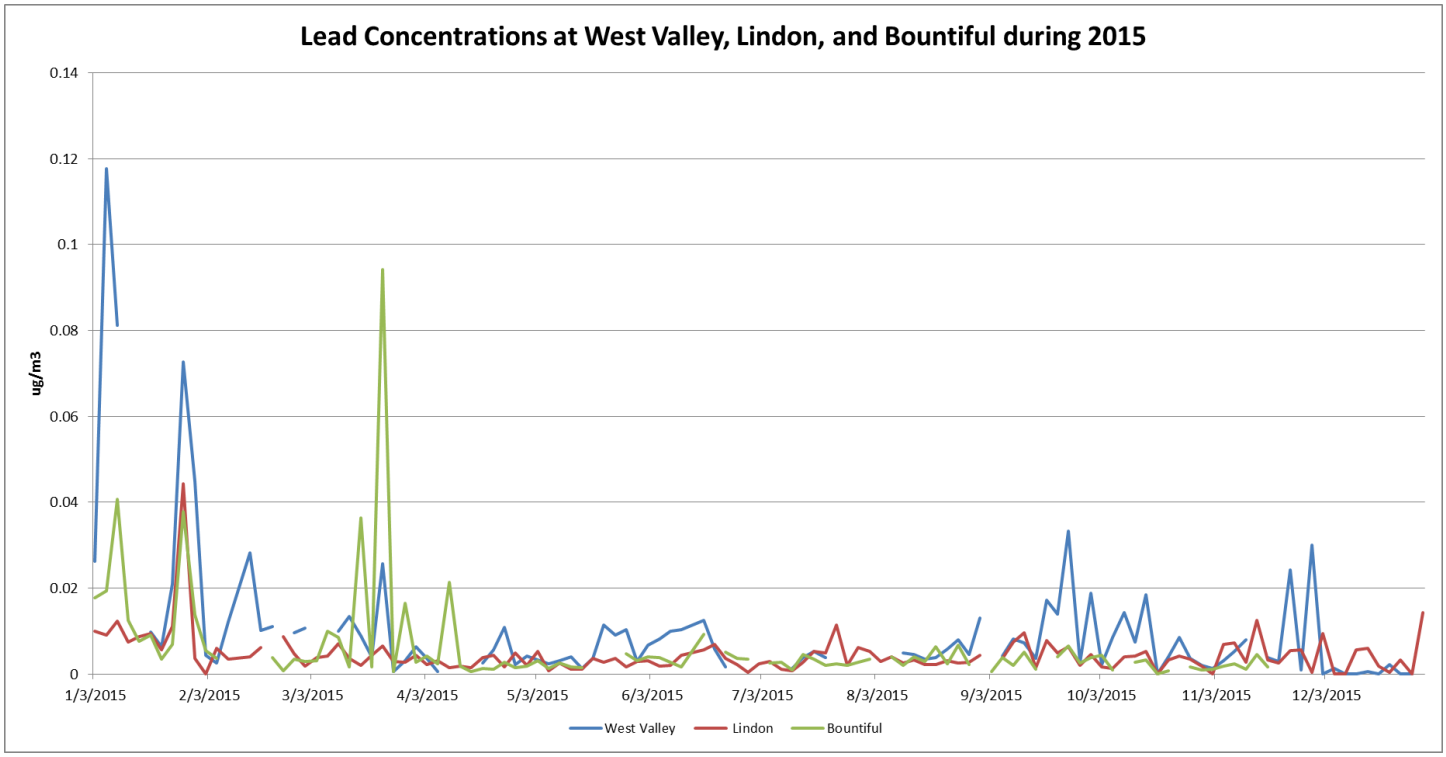
[16] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for 1,3-Butadiene. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1992.

[17] E.J. Calabrese and E.M. Kenyon. Air Toxics and Risk Assessment. Lewis Publishers, Chelsea, MI. 1991.

[18] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Lead (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 2007.

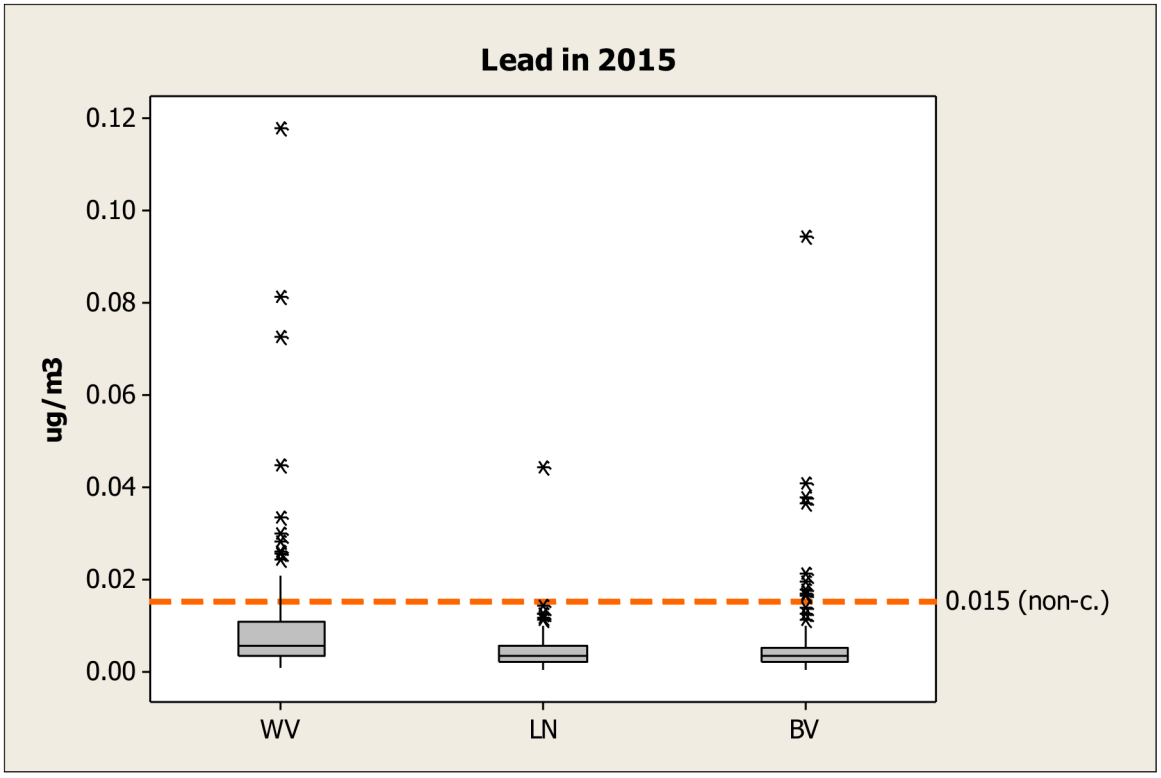
category. Figure 14 shows the lead concentrations in PM_{10} for the Bountiful, Lindon, and West Valley sites. The dashed line represents the non-cancer exposure threshold for lead in ambient air.

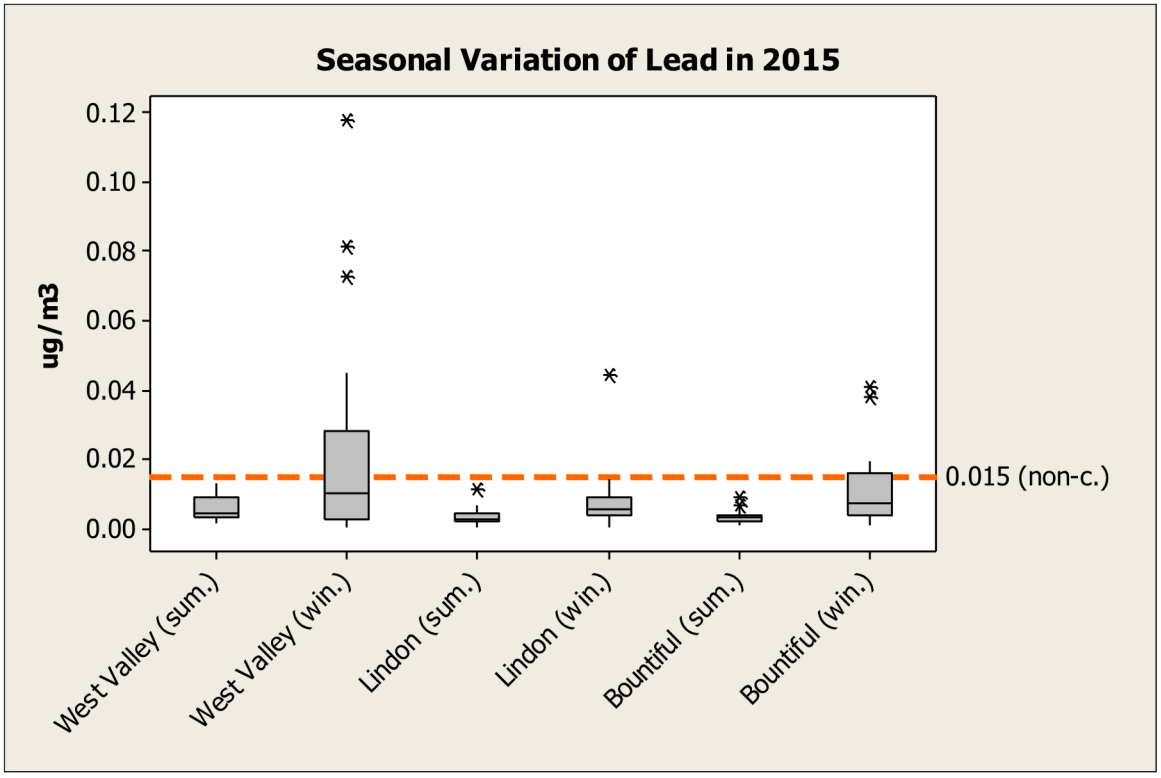
Figure 14. Time series of lead concentrations for West Valley, Lindon, and Bountiful during the 2015 toxics study.



Even though the data collection efficiency was lower at the West Valley site, lead was observed more frequently above the screening level there than in Lindon or Bountiful. Figure 15 shows the boxplots of this analysis, including the seasonal comparisons. The range of lead concentrations detected at Lindon and Bountiful were nearly identical with the exception of the higher number of outlying measurements observed in Bountiful. Overall, West Valley PM_{10} contained consistently higher lead concentrations than the other two sites.

Figure 15. Summary of the lead data collected at West Valley and Lindon in 2015, including seasonal plots.





The overall lead concentrations were higher during the winter months for all three sites. The greatest difference in the median lead concentrations was observed during summer despite the lower overall ambient values. This is likely the direct result of the difference in lead PM distribution across the Wasatch Front. The increased wintertime values are likely due to the accumulation effect happening during inversion episodes. Lead concentrations did not correlate with temperature or wind speed. The pollution and wind roses in supplementary materials section did not reveal any wind-direction pattern associated with days when lead concentrations were elevated.

Although the lead measurements in Utah exceed the chronic exposure threshold with some regularity, it is important to point out that even during the highest observed lead concentrations the State are well below the prescribed lead National Ambient Air Quality Standard (NAAQS) of 0.15 micrograms per cubic meter ($\mu g/m^3$) (three-month rolling average). In addition, although the lead concentrations tended to be higher on weekdays compared to weekends, the difference was not statistically significant.

Generally, mining and lead smelting activity is responsible for the presence of lead in PM_{10}. However, there is not sufficient data to make a direct connection between the higher lead values at West Valley and the current mining activities in the valley. It is possible that the current lead concentrations are a consequence of lead smelters that were present in the Salt Lake Valley between 1900 and the 1970's.

Cadmium

Cadmium is generally emitted into the atmosphere from the incineration of garbage, fossil fuel combustion, and metal (lead, copper, zinc, etc.) smelting. Long-term exposure to cadmium may cause kidney dysfunction. It has also been shown to cause fetal damage and lung cancer in animals, though adequate human exposure data does not currently exist. Cadmium is classified as a possible human carcinogen.[19] The one-in-one-million cancer risk threshold for cadmium compounds is established at $6x10^{-4}$ $\mu g/m^3$.

The sampling campaign of 2015 was not able to consistently detect cadmium compounds in most of the samples. Only 22 and 27 samples collected at the West Valley and Lindon sites, respectively, had detectable amounts of cadmium. Most of the detects at Bountiful (67) were produced by the NATTS program laboratory contracted by the EPA. The EPA contracted lab tended to have greater sensitivity for several of the species than the State laboratory.

Cadmium measurements at both West Valley and Lindon were above the cancer risk threshold of 0.0006 $\mu g/m^3$ with the medians of 0.0007 $\mu g/m^3$ and 0.001 $\mu g/m^3$, respectively. The concentrations at Bountiful had a median of 0.0001 $\mu g/m^3$, much lower than the other two sites. Cadmium concentrations did not differ on weekdays compared to weekends, and they were not correlated with wind speed. At West Valley, cadmium concentrations had a weak negative correlation with temperature, suggesting the

[19] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Cadmium. Draft for Public Comment. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1997.

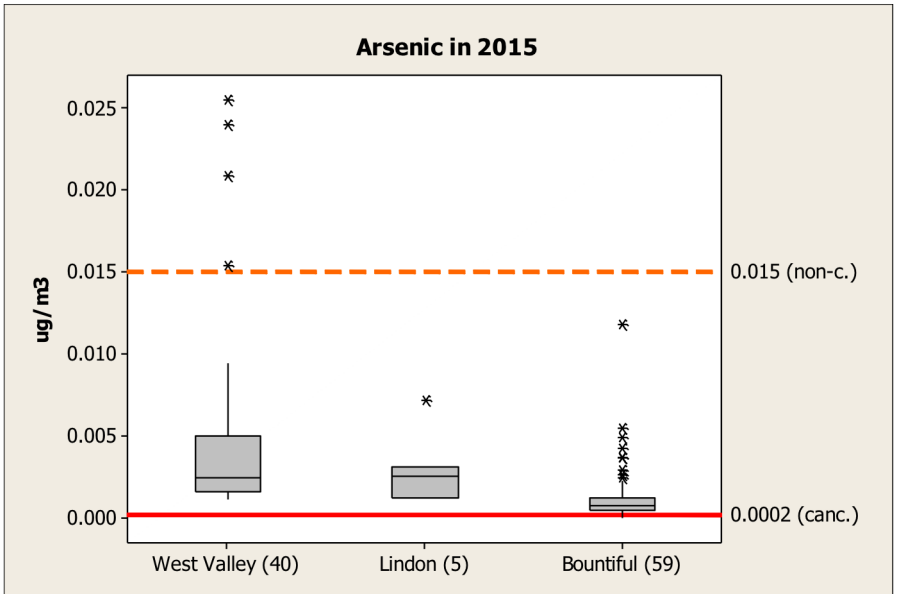
influence of inversions. However, temperature and cadmium concentration were uncorrelated in Lindon and Bountiful. The pollution and wind roses in supplementary materials section did not reveal any wind-direction pattern associated with days when cadmium concentrations were elevated.

Arsenic

Arsenic is a naturally occurring element found throughout the environment. Although the primary exposure route for humans is through ingestion, some arsenic can be inhaled as it attaches to ambient particulate matter. Long-term inhalation exposure to inorganic arsenic has been linked to lung cancer, while ingested arsenic has been shown to cause skin, bladder, and liver tumors. Arsenic is primarily used as a wood products preservative. However, its use in residential construction has been phased out. Arsenic is also used in electronics and semiconductor manufacturing. Inorganic arsenic has been classified as a human carcinogen by the EPA.[20, 21, 22]

Arsenic measurements throughout the study rarely resulted in detections of the pollutant. Due to the low ambient concentrations, the data collection efficiency was 39% (40 samples) at West Valley, and 5% (five samples) at Lindon. As with other metals, the samples collected at the Bountiful site were analyzed using a method with a greater sensitivity, resulting in the collection efficiency of 58% (59 samples). Figure 16 shows arsenic concentrations throughout the study at the three monitoring sites.

Figure 16. Data summary for Arsenic for West Valley, Lindon, and Bountiful in 2015.



[20] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Arsenic (Update). U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 2007.

[21] U.S. Environmental Protection Agency. Health Assessment Document for Inorganic Arsenic. EPA/540/1-86/020. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Washington, DC. 1984.

[22] U.S. Environmental Protection Agency. Integrated Risk Information System (IRIS) on Arsine. National Center for Environmental Assessment, Office of Research and Development, Washington, DC. 1994.

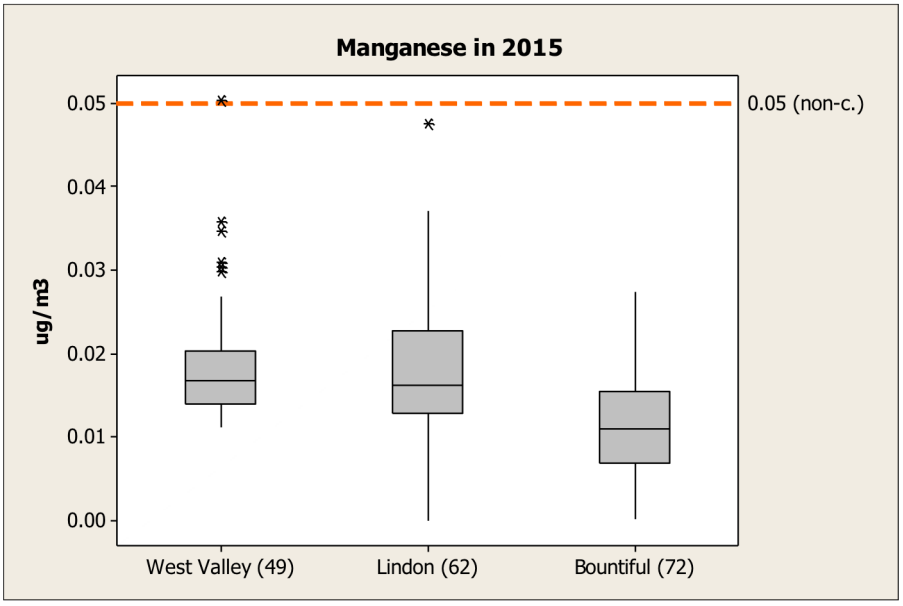
Most of the arsenic measurements were below the non-cancer, but above the cancer risk threshold. The medians between West Valley and Lindon were similar, with a larger variance observed at West Valley. Bountiful arsenic concentrations were well below the other two sites. Current data collection efficiency numbers do not allow for reliable conclusions.

Manganese

Manganese is ubiquitous in the environment. In small doses, it is essential for health. However, prolonged exposure to elevated concentrations of this metal can result in adverse effects on the central nervous system. Manganese exposure can weaken hand-to-eye coordination, reduce reaction times, cause tremors, and lead to impotence and a decreased libido in males.[23]

Large concentrations of manganese are generally observed around ferromanganese smelters, where the greatest exposure to manganese often occurs. A typical ambient air concentration of manganese is approximately 0.02 µg/m^3.[24] Manganese is not classified as a carcinogen for humans. The chronic exposure risk threshold for manganese compounds is 0.05 µg/m^3. Figure 17 shows the manganese concentrations observed during the study at the three sites.

Figure 17. Data summary for manganese for 2015.



[23] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Manganese (Update). Draft for Public Comment. U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1997.

[24] U.S. Environmental Protection Agency. Integrated Risk Information System (IRIS) on Manganese. National Center for Environmental Assessment, Office of Research and Development, Washington, DC. 1999.

Nearly half of all the manganese measurements collected at West Valley and Lindon were below the method detection limit. Data collection efficiency for all three sites was below 75%. With the exception of a single measurement at West Valley, manganese concentrations stayed below the chronic exposure threshold for the year. The medians between the three sites were between 0.01 and 0.02 $\mu g/m^3$. Bountiful values were slightly lower than the other two sites. Lindon had greater variance in manganese concentrations than the other sites. Manganese concentrations did not show a weekday/weekend pattern or significant associations with temperature or wind speed.

Discussion

One of the main goals of the study was to examine the spatial distribution of air toxic pollutants across the Utah and Salt Lake valleys. Because some of the HAPs are closely correlated with specific activities it is plausible to correlate local emission sources to the increased concentrations of a particular HAP at a monitoring site. Of particular significance were formaldehyde and methylene chloride trends at the Bountiful station, as well as lead, metals, and benzene at West Valley.

Bountiful

Bountiful concentrations of formaldehyde behaved uncharacteristically, especially during the winter, for a compound that has a high reactivity in the atmosphere. Observations across the national monitoring network support the view that most of the formaldehyde that is produced throughout the year is observed in the summer. During summer, various VOCs are abundantly emitted from the biosphere along with increased anthropogenic activity resulting in an overall increase of the secondary formation of formaldehyde and other carbonyls. Additionally, as the lifetime of formaldehyde is on the order of 10-12 hours, it can actively spread through the immediate area but does not accumulate in large concentrations.

Higher summertime concentrations of formaldehyde were observed at the Lindon and West Valley sites, but the trend was reversed at the Bountiful station. An identical trend was observed for acetaldehyde, the next closest chemical to formaldehyde in the aldehyde family. It is unlikely that the unusually high concentrations of these compounds are primarily the result of enhancement through trapping in the air mass during inversions. A cursory search through the State's emission inventory database yielded no potential sources that could account for these wintertime (and summertime) values by route of direct emissions.

The most likely explanation for the accumulation of aldehydes in the Bountiful area is that there are significant emissions of close precursors to either of those compounds within five to seven miles of the sampling site. The analysis of wind roses found in the supplementary materials section was inconclusive because of 24-hour average sampling, during which wind direction displayed a typical diurnal wind pattern for the area. The proximity to the Great Salt Lake could also have an effect as the increased albedo over the lake surface could enhance winter photochemistry. If there is enhanced winter photochemistry, it could promote the same chemical processes that occur during the summer.

Although automobile traffic is a known source of formaldehyde, it is unlikely that it is a significant contributor to the formaldehyde/acetaldehyde values at the Bountiful site. Benzene, also closely associated with automobile emissions, was significantly higher in West Valley than in Bountiful and did not follow a trend similar to that found for formaldehyde and acetaldehyde at the Bountiful monitor.

Emissions of unsaturated hydrocarbons, especially propene, could drive the formation of both of the aldehydes as those hydrocarbons react with tropospheric ozone. Further investigation on the emission

rates of unsaturated hydrocarbons is needed to determine whether the contribution from this mechanism is significant enough to effect local formaldehyde and acetaldehyde concentrations.

If formaldehyde and acetaldehyde controls are implemented, they could potentially reduce ozone and particulate pollution in the valley. As both of the compounds actively participate in photochemical ozone production throughout the year, their removal would limit the formation of ozone in the summer time. Because the formation of wintertime secondary $PM_{2.5}$ in Utah is driven by largely the same processes as ozone formation in the summer, reducing formaldehyde and acetaldehyde could have a positive effect on $PM_{2.5}$ conditions during wintertime inversion episodes.

Another pollutant of interest observed at Bountiful was methylene chloride (dichloromethane). As it is not produced by any biogenic process relevant to the area, all of the observed methylene chloride is anthropogenic in nature. The exceedingly high concentration spikes as observed on March 28th, September 30th, and November 8th, 2015 may well be associated with large spills, leaks, or disposal of dichloromethane rich waste from an unidentified source.

Aside from the abnormally high methylene chloride concentration spikes, the day-to-day concentrations of that pollutant were significantly higher than those observed at either of the other two sites. It is likely that the daily above-average values are associated with general operations and activities of a source or sources. The abnormal spikes may represent some control or operating failure, or deliberate disregard of operating procedures and health hazards associated with the pollutant.

Finally, it is possible that the source or sources contributing to high ambient methylene chloride in Bountiful may be a minor source that is not required to declare its toxics emissions to the Division of Air Quality. If so, the source or sources would need to be located in relative proximity to the monitor to produce such extreme ambient values. Further investigation is necessary to determine the source of these emissions.

West Valley

A notable feature in West Valley's HAPs observations was that the site was more heavily impacted by automobile traffic than the other two sites. This is signified by the elevated benzene and butadiene values compared to the other stations. However, it is important to point out that the annual median and distribution range of the benzene values were significantly lower than those observed at the original, pre-NATTS site in West Valley between 2000 and 2002. This is a positive development that indicates the overall improvement in the cleanliness of Utah's motor-vehicle fleet over the past decade and a half.

Lead values observed in West Valley were slightly elevated above those in Bountiful and Lindon. It is likely that old industrial sites, formerly occupied by lead smelters operating in the valley, are having a lasting impact on lead levels in local particulate pollution. As just one example, the former Sharon Steel Company, a Superfund site that was located in Midvale (close to the West Valley monitoring site) had a lead smelter as part of its operation. Former lead smelter sites, crustal material escaping the location of current tailing ponds, and local quarries could all potentially contribute to the increased lead levels in

the valley. Further study is necessary to ascertain the lead sources in the valley. However, it is worth remembering that ambient lead levels are far below the National Ambient Air Quality Standard.

Lindon

Cadmium was the only HAP that was observed higher in Lindon that at any of the other two sites. As cadmium is usually associated with copper, zinc, or lead smelting its presence in Utah Valley is puzzling. It is unlikely, however, that smelting activity in Salt Lake Valley could have a significant impact on the cadmium measurements in Lindon.

An unusually high spike in ethylbenzene observed in Lindon is likely not related to a persistent emission source and is probably sporadic in nature. It is likely the result of an unusual activity in the area, possibly the result of the farm equipment operation that happened in a very close proximity to the sampler.

Overall, Lindon had HAPs levels were equal to or lower than the other two sites. This suggests that Lindon site was much less impacted by industrial and automobile emissions than West Valley or Bountiful.

Even though the wintertime formaldehyde median concentration observed at Lindon was nearly identical to that of West Valley, the range of concentrations was much wider. These occasional higher-than-expected formaldehyde values could lend credence to the possible formaldehyde enhancing effect of the nearby Utah Lake.

As there was no HAPs sampling in Utah Valley prior to this study, no historical comparison is available for the site.

Conclusion

This is the second study of hazardous air pollutants undertaken by DAQ in the last three years. Funding provided by the 2014 legislature for air quality research allowed DAQ to build upon the knowledge gained in its original research study published in June, 2014. An important goal of the current study was to evaluate the differences in pollutant concentrations that might exist among three urban locations on the Wasatch Front.

Variation in pollutant levels were found and the analysis, as presented in this paper, suggests that a follow up suite of measurements could provide important information regarding sources of formaldehyde, acetaldehyde, and methylene chloride. An outline for a new measurement protocol is presented below. While concentrations of lead in the air were observed to be higher at the West Valley monitoring site than in Bountiful or Lindon, the exposure levels are far lower than the National Ambient Air Quality Standard. Analysis of the data indicates that the potential sources of lead in the air may come from industrial activities that no longer operate in the area. The large reduction in benzene and ethylbenzene concentrations over the past fourteen years at the West Valley monitor is a very positive

development and suggests that cleaner automobile engine technology has been effective in reducing levels of this toxic chemical. Given the strong association of this pollutant with automobile emissions in almost all urban areas it seems likely that benzene concentrations throughout the entire Wasatch Front have been reduced considerably over this same time period.

Because the cost of a targeted monitoring campaign requires a significant investment of time and money, DAQ believes that a refined assessment of the organic compounds in the Bountiful area is the appropriate next step to be taken in this process.

Outline of a Potential Source Characterization Study

To investigate sources of the high-concentration organic compounds, particularly formaldehyde, acetaldehyde and methylene chloride, a follow-up study would be of value. Sampling would be conducted over a period of two weeks during winter and summer, respectively, at three different sites in Davis County. Sampling would focus on the Bountiful area since concentrations of the air toxics of interest were highest in this area. The monitoring sites would be strategically selected upwind and downwind of the industrial facilities in the area to determine likely source regions.

To account for the effect of meteorology on air toxics formation and transport in the valley, time-integrated samples would be collected over four distinct time periods. These would include morning (7 a.m.-11 a.m.), midday (11 a.m.-3 p.m.), afternoon (3 p.m.-7 p.m.) and overnight (7 p.m.-7 a.m.) periods, resulting in a total of four samples over a 24-hour period at each site. The sampling times are relatively short to help understand the association between air toxics concentrations and meteorological parameters, such as temperature as well as wind direction and speed, all of which vary over time scales shorter than 24 hours. To maintain consistency with the current study, samples would be collected using similar sampling equipment (ATEC toxic air sampler). To reduce labor effort, DAQ's two existing ATEC samplers could be retrofitted to accommodate additional carbonyl and VOC channels. Another sampler would also be purchased. A total of about 64 samples (60 field and 4 blank samples) would be collected at each site per season and analyzed for VOCs and carbonyls. To help distinguish between vehicular and industrial emission sources, samples would be analyzed for a large suite of VOCs and carbonyls, including markers of vehicular emissions (e.g. benzene, 1,3 butadiene, etc.).

An estimate of the cost associated with the monitoring equipment and chemical analyses is shown below. Assuming that 64 samples will be collected per site per season, the total number of samples to be collected during the sampling campaign is 384.

	Unit price ($/sample)	Unit
VOCs analysis	250	384
Carbonyls analysis	90	384
ATEC 2200-2 toxic air sampler + shipping	19,175	1
Extra carbonyl channel for ATEC 2200 toxic air sampler	3,280	4
Extra VOC channel for ATEC 2200 toxic air sampler	3,530	4
*Total Cost ($)	176,975	

**Excludes samples' shipping cost.*