

# **Spatial and Temporal Patterns of Airborne Toxic Species in Seattle, WA Neighborhoods**

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## **ABSTRACT**

An EPA program was initiated in 2001 that provided airborne toxic measurements at ten different locations in the U.S. The hope was that toxic data obtained in this Pilot Cities Monitoring Program could be used to characterize exposure levels, better understand temporal and spatial trends, as well as, provide information for design of a National Air Toxics Trends Network. The 2001 monitoring program included four urban regions and six small city/rural areas. Seattle, Washington, was one of the four large, urban regions chosen for study. Seattle area measurements were conducted in six different residential neighborhoods. Samples were collected over the course of a year on a one-in-six day schedule. The targeted airborne toxic compounds include VOCs, carbonyls and metals contained in TSP particulate matter. Ambient concentration levels have been tabulated and evaluated for 15 of EPA's "core" urban air toxics. Spatial and temporal patterns of several VOC and carbonyl species are described in this manuscript along with annual average concentrations that can be used for health assessments and model validation.

## **INTRODUCTION**

Hazardous air pollutants (HAPs) that are deemed to adversely affect human health and welfare are regulated under the Clean Air Act. Currently, there are 188 HAPs that are designated for control. However, relatively little is known about human exposure to these toxic materials in the ambient environment. As a result, the U.S. EPA has developed a national air toxics program with the objective being to characterize the impacts of HAPs on public health and the environment<sup>1</sup>. Ambient measurement data are needed to estimate human and environmental exposures to toxics. Several cities/regions across the U.S. are currently determining or soon will be measuring the levels of toxic materials in their environs<sup>2,3</sup>.

At present, it is not feasible to measure all 188 of the HAPs that require control by the CAA. Consequently, EPA has identified a subset comprised of 33 HAPs that should receive the greatest attention. The 33 compounds fall into four chemical categories: volatile organic compounds (VOCs); carbonyl compounds (aldehydes); semi-volatile organic compounds (SVOCs); and metals. Collection and analytical methodologies are constantly evolving for these urban HAPs. At present, several of the HAPs lack approved ambient collection/analytical techniques. The SVOCs are troublesome because they can exist both as gases and as aerosols in the troposphere. Some of the less stable urban HAPs such as acrolein and ethylene oxide are easily lost during collection and storage prior to analysis. This has led to an even shorter list of toxic compounds that can be reliably measured in the urban environment. EPA has categorized these as urban air toxic (UAT) "core" species. There are nine VOCs, two carbonyls, and seven metals listed as "core" toxics (Table 1).

Table 1. Urban air toxic "core" species.

VOCs	Carbonyls	Metals
Benzene	Acetaldehyde	Arsenic
1,3-Butadiene	Formaldehyde	Beryllium
Carbon tetrachloride		Cadmium
Chloroform		Chromium
Dichloromethane		Lead
1,2-Dichloropropane		Manganese
Tetrachloroethylene		Nickel
Trichloroethylene		
Vinyl chloride		

In this manuscript, we report ambient concentration data for the VOC and carbonyl compounds listed in Table 1. In addition, the spatial and temporal behavior of the Seattle air toxics will be discussed. UAT sampling was initiated in 2000 with samples collected in two residential areas of Seattle (Beacon Hill and Georgetown). The toxic monitoring program expanded in 2001 with the addition of four new sites for a total of six monitoring locations. The new sampling sites were in neighborhoods north (Lake Forest Park and Maple Leaf), east (Lake Sammamish) and south (Sea-Tac) of Seattle's urban core. Seattle served as one of EPA's ten Pilot Cities for urban toxics studies in 2001<sup>4</sup>. Seattle's toxic sampling network dropped to three sites in 2002 and is now down to only the Beacon Hill site, which has been designated as a National Air Toxics Trend Site (NATTS). Future sampling at the Beacon Hill trends site will provide a record of changes in toxics concentrations over time in Seattle.

## EXPERIMENTAL

**Analytical Methods Summary.** Twenty-four hour integrated ambient air samples were collected at a frequency of every six days at all air toxics monitoring sites. Approximately 60 ambient air samples collected at each of the sites in stainless steel canisters were analyzed for VOCs using Compendium Method TO-14A (GC-FID/ECD).

Ambient air samples collected on DNPH-coated silica cartridges at each site were analyzed for carbonyl compounds using Compendium Method TO-11A (HPLC). The VOC and carbonyl analyses were performed by Washington State University (Laboratory for Atmospheric Research). Commercial ZonTech instruments were employed for VOC and carbonyl field sample collections at all of the sites. The UAT “core” metals data were obtained from quartz fiber TSP filters analyzed by ICP-MS (Compendium Method IO-3.5). A more detailed description of the analytical procedures follows.

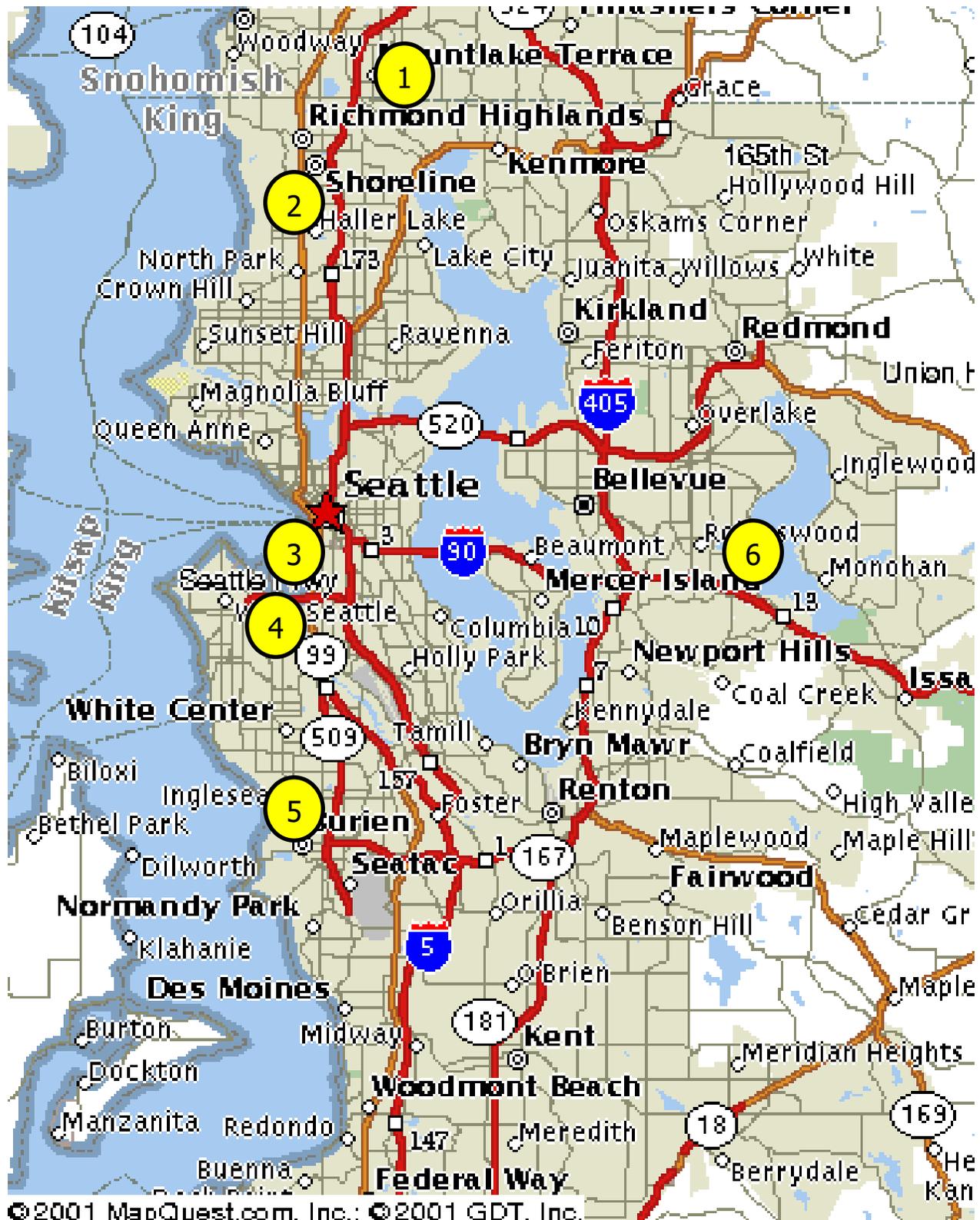
**Sampling sites.** Sampling locations employed in this study were selected to reflect potential "community-oriented" population exposure. Samplers represented average concentrations within a 0.5 to 4.0km<sup>2</sup> area, which is termed "neighborhood-scale". Neighborhood-scale measurements provide population exposures that can be used to estimate potential long-term risk since they are thought to reflect units of typical urban population exposures. All sampling stations met US EPA's guidelines for set back distances, inlet heights, and other siting considerations<sup>5</sup>. This population-oriented approach is analogous to the core network for PM<sub>2.5</sub> and the National Air Monitoring Station (NAMS) trend network for the criteria pollutants. The six air toxics monitoring stations were sited to provide air quality information relative to mobile, industrial, wood smoke, and other area sources. Stations were located in distinctly different sub-regions within the urban area, so that spatial variability of air toxics concentrations could be characterized.

The six sites (see Figure 1) were located as follows:

- Lake Forest Park (LF) is a suburb approximately 24 km north of downtown Seattle. The site had been employed as a PM<sub>2.5</sub> monitoring station in past years. Emissions from residential wood burning and mobile sources were expected to be prominent at this site.
- The Maple Leaf Reservoir (ML) site was in the middle of the Maple Leaf residential community approximately 16 km north of downtown Seattle. It was surrounded by a region of high population density that included a mix of urban emission sources.
- Washington Dept. of Ecology's Beacon Hill (BH) sampling site is located in a controlled-access, water reservoir impoundment at the top of a hill southeast of downtown Seattle. An observer looking to the west can see King County Airport, Interstate Highway 5, and Seattle's main industrial area.
- The Georgetown (GT) site was established in a WA Dept. of Transportation (DOT) facility that is located a short distance north of the Georgetown residential neighborhood. Seattle's main industrial complex lies to the north of the Georgetown site.
- The South Seattle site was located just north of the Seattle-Tacoma International Airport (ST), which is approximately 32 km south of downtown Seattle. The site was impacted by mobile sources from a network of nearby freeways and congested streets.

- The easterly site was located roughly 16 km from downtown Seattle near Lake Sammamish (LS). This site was intended to measure air quality in the rapidly expanding residential areas to the east of the urban center.

Figure 1. Map showing Seattle area sites: 1) Lake Forest Park; 2) Maple Leaf; 3) Beacon Hill; 4) Georgetown; 5) Sea-Tac; 6) Lake Sammamish



**VOC sampling.** The XonTech 910A samplers were programmed to fill a 6-liter passivated, stainless steel canister to about 1.5 atm. (~ 10 L) over the collection period. At the end of the 24-hour collection period, sample canisters were removed from the collection system and shipped to Pullman WA for VOC analysis

**Carbonyl sampling.** XonTech 925PC carbonyl samplers were employed for determination of formaldehyde and acetaldehyde. A measured amount of air was passed through a silica gel cartridge impregnated with 2, 4-dinitrophenyl hydrazine (DNPH). The cartridges were sealed and shipped to Pullman for analysis. An ozone scrubber was attached to the inlet line.

**VOC analyses.** A Hewlett Packard 5890 gas chromatograph was used for VOC analyses. A DB-1 fused silica capillary column (J & W Scientific) was employed to resolve VOCs in the C<sub>3</sub>-C<sub>12</sub> molecular weight range. The column effluent was split on the downstream end with about 90% of the flow to an FID and 10% to an ECD. The normal carrier gas flow system was modified to include a freeze-out trap for concentrating organics in the ambient air sample. Nitrogen at 1 cm<sup>3</sup> min<sup>-1</sup> was used as the carrier gas with the DB-1 fused silica capillary column. Optimum results were obtained by temperature programming the column oven from -50 to 150 °C at 4 °C min<sup>-1</sup>.

Air from the sample canister was drawn through the cryogenic trap into an evacuated cylinder. The sample volume was determined by measuring the pressure change in the cylinder. Normally, 750 ml of air was passed through the freeze-out trap, which was maintained at -186 °C (liquid oxygen). The trap itself consisted of a 3.18 mm x 15.24 cm stainless steel tube containing 60-80 mesh glass beads. This trap was attached to the gas chromatograph via a mini-volume gas-sampling valve (Valco Inst.).

Peak identities for the pure hydrocarbons (e.g. benzene and 1,3-butadiene) were based on comparison of retention times and mass spectra with known standards. The concentration of the hydrocarbons was determined by ratioing the instrument response for each peak to that recorded for a known concentration of 2,2-dimethylbutane. The concentration of the 2,2-dimethylbutane standard was assigned through comparison with a NIST purchased propane SRM. Quantitation of the halogenated hydrocarbons was based on a comparison of peak area responses to a certified TO-14 standard purchased from a commercial supplier. Each chromatogram was visually examined to ensure data quality.

**Carbonyl analysis.** Exposed DNPH cartridges were eluted with acetonitrile (ACN), the elutant volume was measured, and the hydrazones in the eluted samples were quantified by a Hewlett Packard 1090 series II High Performance Liquid Chromatograph with a diode array detector (DAD) operated at 360 nm. Peak separation was accomplished with a 10 cm OD-MPS reverse phase column (Supelco) with a gradient elution ranging from 50:50 to 30:70 H<sub>2</sub>O:ACN over the period from 5 to 17 minutes. A 20 µL sample loop was employed and the total solvent flowrate was 0.8 mLmin<sup>-1</sup>. Qualitative identification of the hydrazones was performed by matching the retention times with those of known standards. For quantitation, pure carbonyl hydrazone derivatives were prepared or purchased. High concentration master standards were

prepared for each carbonyl of interest and these were then used to prepare a set of working standards ranging from 0.2 to 5 mg mL<sup>-1</sup>. A running calibration for relating peak areas to hydrazone concentrations was formed by taking the running mean of the standard analyses (area counts for each analyte) over the time period the analyses were conducted. Ambient carbonyl concentrations were calculated from the recorded peak area, eluant mass, and air volume sampled.

**Quality assurance.** Quality assurance activities in the 2001 UAT sampling program included duplicate sample collections at the Beacon Hill site. This provided a measure of sampling uncertainty. In addition, many replicate analyses were performed which were used to judge analytical uncertainty. Relative percent difference (RPD) was the statistical measure used to judge comparability of duplicate and replicate analyses. Often a replicate analysis was carried out on the sample and/or the duplicate. This then gave as many as four analyses (sample and replicate plus duplicate and replicate) for a single 24-hr collection period at Beacon Hill. When comparing the results from three or more analyses, relative standard deviation (RSD) was used to calculate precision.

Table 2 shows the mean normalized absolute bias (absolute RPD and RSD) for the carbonyl and VOC species. The sampling uncertainties (sample-duplicate ARPD) range from a low of 7% for carbon tetrachloride to 30% for 1,3-butadiene. This shows the precision achieved with two side-by-side samples collected simultaneously. The analytical uncertainty (replicate ARPD) was somewhat lower ranging from 4% for the carbonyls to 26% for 1,3-butadiene. This is not unexpected because this measures the precision of two analyses of the same sample. The ARSD determined from multiple analyses on the sample/duplicate pair (two analyses of sample plus two analyses of duplicate which ideally would give four identical results) was less than 20% for all species except 1,3-butadiene (28%). Table 2 includes a listing of minimum detection levels (MDL) as determined by standard EPA procedures<sup>6</sup>.

Table 2. Precision

	Sample-Duplicate ARPD (%)	Replicate ARPD (%)	Sample/Duplicate/Replicates ARSD (%)	MDL (ppbv)
Benzene	19	17	18	0.014
1,3-Butadiene	31	26	28	0.021
Carbontetrachloride	7	7	6	0.010
Chloroform	16	6	9	0.020
Tetrachloroethylene	12	10	10	0.012
Trichloroethylene	22	7	12	0.015
Acetaldehyde	13	4	11	0.045
Formaldehyde	13	4	9	0.108

## RESULTS

Sample recoveries were good at all six of the Seattle area sampling sites resulting in about 60 samples each and approximately 360 samples in which to examine temporal

and spatial UAT behavior in Seattle. Of the UAT “core” VOCs, all but 1,2-dichloropropane and vinyl chloride consistently exhibited measurable concentrations. Chromatographic separation of dichloromethane proved to be difficult and as a result it won’t be discussed in this manuscript.

Tables 3-10 contain statistical summaries of air toxics data collected in Seattle. When reporting statistics in this manuscript, we have chosen to treat concentrations below the MDL as valid, rather than assigning a value such as one-half the MDL. Using the measured value vs one-half the MDL has little effect on the statistics reported in Tables 3-10. The 95% confidence interval was calculated with the MS EXCEL function.

Benzene is widely used as an industrial solvent as well as being a component of gasoline and auto exhaust. The benzene annual mean for all samples collected in Seattle was 0.43 ppbv. The maximum 24-hr average concentration recorded was 2.22 ppbv

Table 3. Summary statistics for benzene at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.52	0.09	0.42	1.65	0.14	61
Maple Leaf	0.35	0.04	0.34	0.67	0.12	62
Beacon Hill	0.41	0.06	0.35	1.70	0.10	69
Georgetown	0.54	0.11	0.42	2.22	0.10	66
Sea-Tac	0.33	0.04	0.28	0.95	0.10	63
Lake Sammam.	0.37	0.04	0.38	0.68	0.11	57
Seattle Average	0.43	0.03	0.35	2.22	0.10	378

1,3-Butadiene is used in rubber manufacturing processes and is emitted from combustion sources. The main source of 1,3-butadiene in Seattle is expected to be mobile source emissions. This is reflected by a fairly uniform annual mean of 0.05 ppbv throughout the Seattle area.

Table 4. Summary statistics for 1,3-butadiene at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.06	0.01	0.034	0.50	0.01	61
Maple Leaf	0.04	0.01	0.026	0.24	0.01	62
Beacon Hill	0.04	0.01	0.035	0.27	0.01	69
Georgetown	0.05	0.01	0.040	0.23	0.01	66
Sea-Tac	0.05	0.01	0.032	0.33	0.01	63
Lake Sammam.	0.05	0.01	0.033	0.37	0.01	57
Seattle Average	0.05	0.01	0.033	0.50	0.01	378

Carbon tetrachloride usage has been greatly curtailed in recent years due to its contribution to stratospheric ozone depletion. However due to its long lifetime in the troposphere, ambient concentrations remain relatively constant at about 0.100 ppbv. As

can be seen in Table 5, our Seattle area average for 375 samples was 0.099 ppbv. At each of the six sites, we did occasionally record elevated levels of carbon tetrachloride which implies that there are still some local emissions.

Table 5. Summary statistics for carbon tetrachloride at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.102	0.004	0.102	0.162	0.062	61
Maple Leaf	0.097	0.003	0.098	0.124	0.068	62
Beacon Hill	0.096	0.003	0.099	0.127	0.070	69
Georgetown	0.103	0.004	0.104	0.182	0.072	65
Sea-Tac	0.099	0.003	0.100	0.140	0.067	63
Lake Sammam.	0.099	0.004	0.100	0.148	0.066	55
Seattle Average	0.099	0.004	0.101	0.182	0.062	375

Chloroform concentrations were very similar at the Lake Forest Park, Georgetown, Sea-Tac and Lake Sammamish sites with annual means of 0.030 ppbv or less. The annual means were significantly higher at the Beacon Hill and Maple Leaf sites resulting in a Seattle area annual mean chloroform concentration of 0.034 ppbv.

Table 6. Summary statistics for chloroform at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.030	0.004	0.023	0.080	0.011	61
Maple Leaf	0.047	0.009	0.035	0.185	0.008	62
Beacon Hill	0.044	0.007	0.031	0.143	0.011	69
Georgetown	0.029	0.005	0.020	0.110	0.010	65
Sea-Tac	0.026	0.004	0.020	0.062	0.007	63
Lake Sammam.	0.026	0.004	0.022	0.093	0.001	55
Seattle Average	0.034	0.003	0.024	0.185	0.001	375

Annual mean concentrations of the chlorinated ethylenes were similar. Trichloro- and tetrachloroethylene are employed as industrial solvents. They are used in cleansing processes such as degreasing of metals and dry cleaning. Highest annual means for tetra- and trichloroethylene (0.054 and 0.071 ppbv) were recorded at the Georgetown site. The annual means for the two halocarbons at the other five Seattle area sites ranged between 0.021 and 0.039 ppbv.

Table 7. Summary statistics for tetrachloroethylene at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.036	0.011	0.026	0.267	0.004	61
Maple Leaf	0.031	0.008	0.021	0.181	0.005	62
Beacon Hill	0.023	0.005	0.016	0.116	0.003	69
Georgetown	0.054	0.012	0.039	0.280	0.004	65
Sea-Tac	0.021	0.006	0.017	0.113	0.003	63
Lake Sammam.	0.026	0.008	0.013	0.185	0.004	55
Seattle Average	0.032	0.004	0.020	0.280	0.003	375

Table 8. Summary statistics for trichloroethylene at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.031	0.006	0.027	0.107	0.003	60
Maple Leaf	0.039	0.006	0.030	0.119	0.007	62
Beacon Hill	0.035	0.005	0.033	0.138	0.003	69
Georgetown	0.071	0.018	0.045	0.462	0.010	65
Sea-Tac	0.032	0.013	0.024	0.408	0.004	63
Lake Sammam.	0.026	0.007	0.022	0.181	0.004	55
Seattle Average	0.040	0.006	0.030	0.462	0.003	374

The two carbonyl compounds measured in this study have primary and secondary sources. Care must be exercised when sampling formaldehyde because of the ubiquitous nature of sources. Insulating foams, plywood resins, carpet materials all emit formaldehyde. Formaldehyde is produced photochemically via the same processes that generate ozone and other smog products. Acetaldehyde is produced as an oxidation product in tropospheric photochemistry and is a common product of microbial degradation of organic materials. Annual mean concentrations of the two carbonyls exceeded any of the other species monitored in this study. Formaldehyde was the largest at 1.08 ppbv with acetaldehyde somewhat lower at 0.69 ppbv.

Table 9. Summary statistics for acetaldehyde at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.66	0.07	0.6	1.50	0.21	60
Maple Leaf	0.63	0.08	0.6	2.3	0.13	56
Beacon Hill	0.74	0.14	0.6	2.5	0.11	58
Georgetown	0.67	0.11	0.6	2.61	0.14	59
Sea-Tac	0.76	0.09	0.6	2.09	0.21	61
Lake Sammam.	0.71	0.12	0.7	3.34	0.33	57
Seattle Average	0.69	0.07	0.6	3.34	0.11	351

Table 10. Summary statistics for formaldehyde at Seattle area sites.

Site	Mean (ppbv)	95 % CI (ppbv)	Median (ppbv)	Max (ppbv)	Min (ppbv)	n
Lake Forest	0.89	0.10	1.1	2.30	0.14	61
Maple Leaf	1.03	0.13	1.0	2.39	0.22	54
Beacon Hill	1.35	0.17	0.9	3.70	0.20	66
Georgetown	1.20	0.17	0.9	3.77	0.08	67
Sea-Tac	1.08	0.12	0.7	2.44	0.04	63
Lake Sammam.	0.85	0.15	1.1	3.12	0.07	59
Seattle Average	1.08	0.06	1.0	3.77	0.04	370

## DISCUSSION

Goals of this study were to establish current baseline levels of the UAT “core” species and to examine the spatial and temporal behavior of airborne toxics in Seattle. These data will be combined with similar information collected in other Pilot Cities to provide an understanding of air toxics levels across the U.S. Comparing pollutant concentrations from one city to another is difficult due to differing site characteristics and analytical procedures. The Pilot Cities program attempted to make things as comparable as possible through a comprehensive QA plan that required each participant to follow a strict set of guidelines<sup>7</sup>. As the Pilot Cities results become available, residents of Seattle will be able to compare their air quality with other cities in the U.S.

Table 11 summarizes the annual mean concentrations of “core” VOC species in Seattle. The average concentrations ranged from 1.08 ppbv for formaldehyde to 0.032 ppbv for tetrachloroethylene. As a general indication of how Seattle’s air quality compares with other U.S. cities, Table 11 shows values reported in various U.S. EPA summaries. In most cases, Seattle’s mean concentrations appear to be lower than other cities.

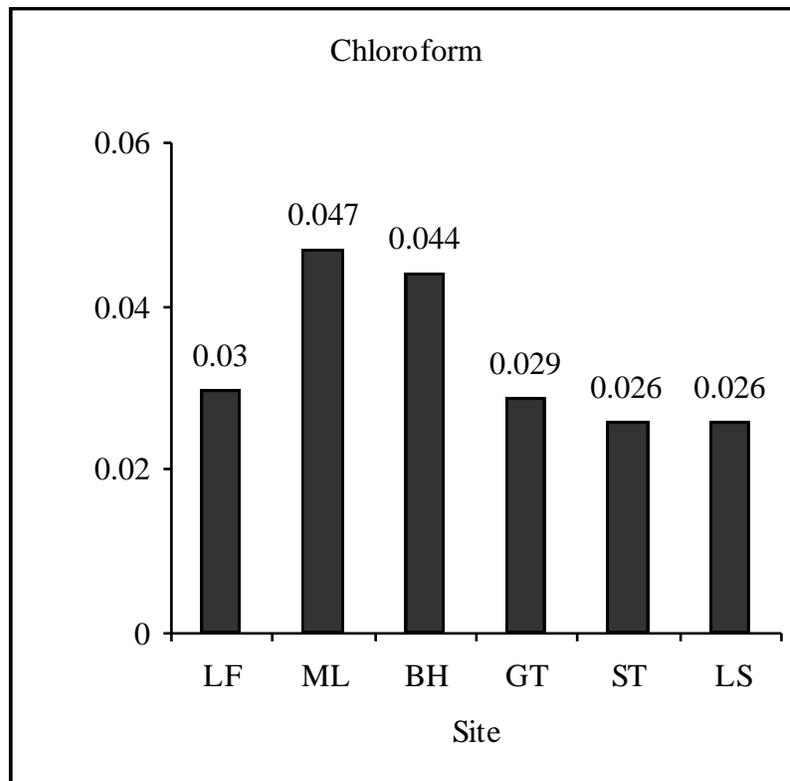
Table 11. Air toxic concentrations in Seattle and other U.S. cities.

	2001 measured Seattle mean (ppbv)	U.S. cities mean <sup>8</sup> (ppbv)	2001 UAT mean <sup>8</sup> (ppbv)
Benzene	0.43	0.65	0.70
1,3-Butadiene	0.05	0.38	0.13
Carbon tetrachloride	0.099	0.14	0.092
Chloroform	0.034	0.10	0.057
Tetrachloroethylene	0.032	0.17	0.085
Trichloroethylene	0.040	0.12	0.246
acetaldehyde	0.69	1.63	1.32
Formaldehyde	1.08	4.21	3.96

Spatial variation in the annual mean concentrations for all of the air toxics at the six Seattle sites was not very large. With a few exceptions, annual means varied by less than a factor of two throughout the network for each of the individual VOCs. Carbon tetrachloride exhibited negligible spatial variation with an annual mean close to 0.100 ppbv at all six sites. The same was true for 1,3-butadiene with an annual mean of close to 0.05 ppbv at the six sites. Acetaldehyde annual means varied between 0.63 and 0.76 ppbv while formaldehyde and benzene annual means showed somewhat more variability but still less than a factor of two.

Chloroform, tetrachloroethylene and trichloroethylene exhibited the largest spatial differences. Figure 2 shows the chloroform spatial pattern. Annual average concentrations at Maple Leaf and Beacon Hill were approximately double the values recorded at the other four sites. The two sites with elevated chloroform levels are located close to drinking water treatment facilities. It is well known that trihalocarbons such as chloroform are produced when water containing humic substances is chlorinated. Thus, it is very likely that the elevated chloroform levels at Maple Leaf and Beacon Hill are the result of emissions from the nearby water treatment reservoirs.

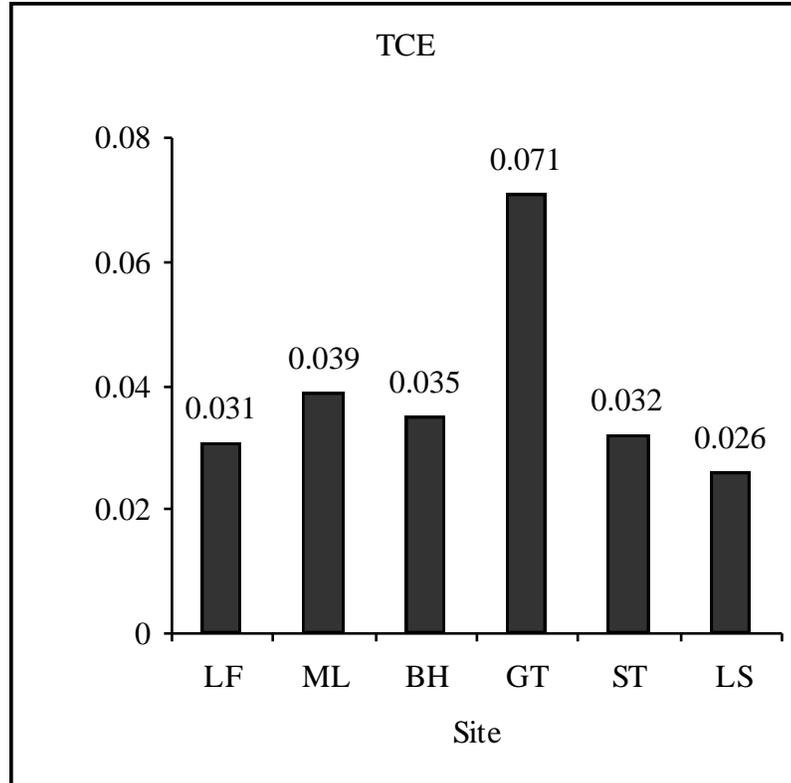
Figure 2. Annual average chloroform concentrations at Seattle sites.



Tetrachloroethylene and trichloroethylene annual average concentrations were significantly higher at the Georgetown neighborhood site. As can be seen in Figure 3, the trichloroethylene annual average was nearly twice that observed at the other five sites.

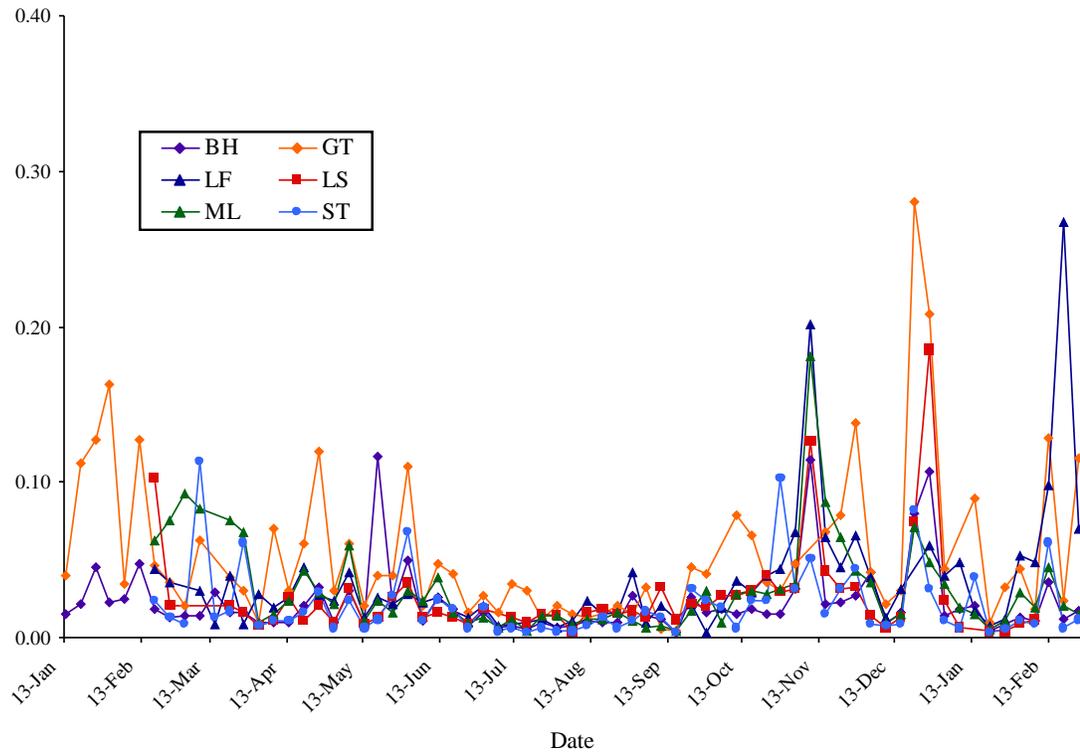
The elevated levels of these two halocarbons at the Georgetown site are likely the result of its close proximity to Seattle's main industrial area.

Figure 3. Annual average trichloroethylene concentrations at Seattle sites.



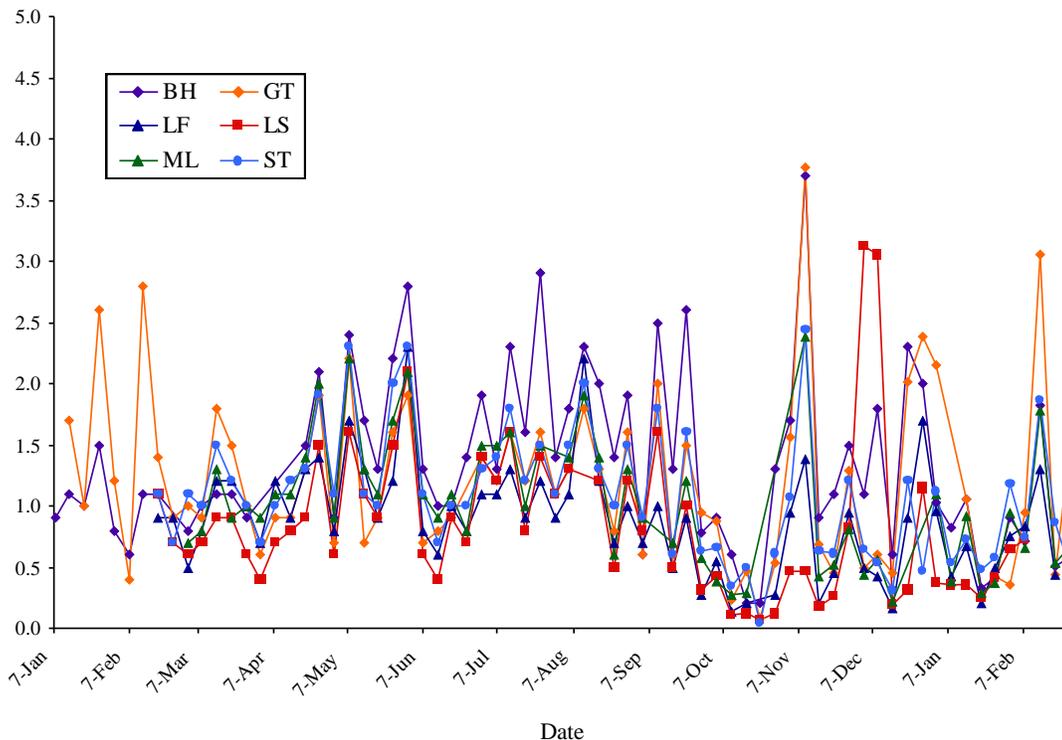
Defining accurate temporal patterns with only one year of data is problematic because anomalous weather and/or other factors could have been present during the short study period. However, it does appear that most of the species measured have winter maxima and lower concentrations in the summer. This is illustrated in Figure 4, which shows the temporal trend in tetrachloroethylene at the six sites during 2001. Ambient concentrations at all of the Seattle sites are lowest from early June through about mid-September. During the winter and spring average concentrations are elevated due to numerous days with high readings. During these seasons there is a lot of variation in concentration from one sampling day to the next. These temporal patterns are likely the result of ventilation features in the Puget Sound region of Washington State. The wintertime meteorology is dictated by the regular passage of storm systems with wind and rain. Between the frontal passages, stagnant wintertime conditions can lead to the buildup of pollutant levels. Seattle's summer time meteorology is conducive to good turbulent mixing and lower air toxic concentrations.

Fig. 4: Daily concentrations of tetrachloroethylene at the six sampling sites



Formaldehyde is the exception to the general rule of summertime concentration minima. As can be seen in Figure 5, the pattern of low summertime concentrations seen with tetrachlorethylene has been replaced with what appears to be a peaking of formaldehyde during this time period. This implies that secondary production of formaldehyde is important during the warm summer and early fall months in Seattle.

Fig. 5: Daily concentrations of formaldehyde at the six sampling sites



## CONCLUSIONS

This work has provided the first measurements of airborne toxics in the Pacific Northwest's largest city. In general, air toxic levels are lowest during the summer months and reach a maximum in the wintertime. With the exception of a few of the chlorine containing VOCs, concentrations of the air toxics were quite similar at the six Seattle area sites. These data will serve as a baseline for evaluating future trends of air toxics in Seattle. As mentioned earlier, the Beacon Hill site has been designated as a National Air Toxics Trend Site and it is expected that measurements will continue well into the future. In future years, if emissions of the "core" air toxics are reduced, a comparison of the ambient measurements reported in this manuscript and those monitored in ensuing years should help to verify the emissions reductions.

A primary objective of EPA's National Air Toxic Assessment program is to better understand human exposure to hazardous air pollutants. The 2001 measurement data obtained in Seattle can be utilized by health professionals to support risk assessments due to exposure to several hazardous pollutants. Liu and co-workers have reported some initial risk factors for the Seattle neighborhoods based on measurements obtained in this study<sup>9</sup>.

Another important use for the data will be to validate air quality modeling in the Seattle region. We are currently providing daily, air quality forecasts for the Seattle and

western Washington region. The AIRPACT modeling system ([www.AIRPACT.wsu.edu](http://www.AIRPACT.wsu.edu)) now includes predicted hourly concentrations of several of the “core” air toxics. The ambient measurements will provide a test of model accuracy. We will employ dispersion modeling techniques as well as more sophisticated chemical transport models to understand source-receptor relationships at individual sites in Seattle.

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