

**PASSIVE AMBIENT AIR TOXICS MONITORING IN THE HOUSTON-
GALVESTON AREA:**

**Phase I. Determination of Optimum Sampling Conditions;
Phase II & Phase III. Temporal and Spatial Monitoring;
Phase III Supplementary Monitoring**

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The project has five phases as listed below. This report contains Phase I, II, and III. The final reports can be found at US/EPA Website under:
<http://www.epa.gov/ttn/amtic/files/ambient/passive>.

Phase I. Determination of Optimum Sampling Conditions

Phase II. Year-long Temporal Passive Monitoring at High and Low TRI Emissions; Aldine and Clinton areas

Phase III. Community-based Spatial Monitoring; Aldine, Clinton, and Deer Park

Phase III Supplementary Monitoring

Phase IV. Spatial Analysis of Passive VOCs from the Community-Based Network in Deer Park near Houston Ship Channel, TX

Phase V. Statistical Analysis of Passive VOCs in Aldine and Clinton near Houston, TX

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PROJECT SUMMARY

The Houston-Galveston metropolitan area has a relatively high density of point and mobile sources of air toxics. Determining and understanding the relationship between emissions and ambient air concentrations of air toxics is important for evaluating the potential impact on public health and formulating effective regulatory policies to control this impact, both in this region and elsewhere. However, the conventional air monitoring approaches are quite limited with regard to expense and siting limitations, and as a result, limited monitoring data is available for proper estimation of urban ambient air toxics and the related human health exposure assessments. In order to circumvent these difficulties, this project seeks to demonstrate that the passive sampling devices (PSDs) can be used at a low cost as a simple monitoring device for the long-term geographical sampling of low ambient hazardous air pollutants (HAPs) in urban areas.

Passive samplers were originally developed for personal exposure assessments, but due to their low cost and ability to be easily used, they have been increasingly used to monitor a broad range of outdoor HAPs (Chung, K. 2000). At the same time, the passive samplers have been tested as an alternate method to conventional air sampling methods, such as auto GC and canisters. Specifically, the passive samples have been tested for their stability and effectiveness in the laboratory and community-based outdoor settings to measure low concentration ambient HAPs. Among the passive samplers, charcoal-based organic vapor monitors (OVMs) primarily have been tested, including recent performance tests with field sampling in Houston, TX (Chung et al., 1999; Morandi and Stock, 2000). In this study, 3M charcoal-based OVMs were selected to monitor several organic compounds that have been identified as being potentially harmful to the public's health.

There were three Phases associated with this project: (1) Determination of Optimum Sampling Conditions; (2) Temporal Variability Study, and (3) Spatial Variability Study. Phase I involved a field evaluation of 3M Organic Vapor Monitors (OVMs) involving limited comparisons with continuous GC measurements, an assessment of sampler precision, and a determination of optimum sampling duration. Phase II involved a year-long comparison (samples collected every 12 days) of measurements at two air monitoring stations (high and low TRI areas) with measurements at nearby census-tract centroids, and a direct comparison with simultaneous canister sampling. Phase III included an investigation of spatial variation of volatile organic chemicals (VOCs) in three distinct neighborhoods, and an evaluation of the representativeness of simultaneous measurements at central monitoring stations. For the completion of Phase III, supplementary monitoring was conducted for additional information.

Ambient Air Toxics in Houston-Galveston Area with High and Low TRI Emissions – A Pilot Study of Temporal and Spatial Concentrations Using Passive Sampling Devices (PSDs)

Phase I: Determination of Optimum Sampling Conditions

1. Introduction

The specific objectives of the first Phase of this project were to: 1) demonstrate that the 3M 3500 Organic Vapor Monitor (OVM) can be used to measure short-term (24 to 72 hour) concentrations of a target list of volatile organic compounds (VOCs) at one ambient air monitoring site; 2) compare the concentrations (and masses) measured with unmodified vs. modified OVMs; 3) compare the concentrations measured with OVMs vs. available comparison methods at the site; and 4) determine the optimal sampling time for the unmodified OVMs to be used in subsequent Phases.

The targeted VOCs include: benzene, 1,3-butadiene, carbon tetrachloride, chloroform, chloroprene, ethyl benzene, p-dichlorobenzene, limonene, methylene chloride, methyl tert-butyl ether (MTBE), naphthalene, α -pinene, β -pinene, styrene, tetrachloroethylene, toluene, trichloroethylene, o-xylene, and m/p-xylene.

II. Sampling Site

The ambient air monitoring site chosen for Phase I was the Clinton Drive site, operated by the Texas Natural Resource Conservation Commission (TNRCC). Additional site description is provided in Appendix A. As indicated, air quality at this site may be affected by proximity to Houston Ship Channel industries, roadways, and railroad shipments. The predominant wind direction is from the southeast. Stainless-steel canister samples are collected every six days (midnight to midnight). In addition, the TNRCC operates a continuous gas chromatograph (GC) at the site, which provides hourly-averaged concentrations for a number of VOCs, including some compounds monitored by the OVMs (benzene, 1,3-butadiene, ethyl benzene, styrene, toluene, o-xylene, and m/p-xylene).

III. Methods

Sampling

All OVM sampling was conducted on the roof of the trailer. An all-metal sampling stand was assembled, with a wire-mesh tray placed near the top (five feet above the roof), and an aluminum foil-covered top cover to protect the samplers from rain and direct sunlight. The OVMs were suspended from the wire-mesh tray, at least six inches below the top cover. Flow of air was unrestricted from all sides. Some OVM cans containing field blanks (FBs) were in a tray placed lower in the stand.

Triplicate sampling was performed with both unmodified and modified OVMs. The unmodified samplers were 3500 OVMs obtained directly from 3M, without labels affixed to the badges. The lot number employed for all Phase I sampling was # 1127-10 (expiration 11/02). The modified samplers were OVMs from the same lot that were altered by halving the original diffusion path length by placing the charcoal wafer on top of a custom-machined teflon disk, and by replacing the original windscreen with a Teflon membrane filter with reinforced ring (37 mm, 2.0 um PTFE membrane, Pall Corp., Ann Arbor, MI).

Ambient air monitoring was conducted during three 3-day sampling events: 1) September 21-24, 2001, 2) September 26-29, 2001 and 3) October 2-5, 2001. During each of these sampling events three OVMs of each type were exposed for either 24, 48 or 72 hours. For each exposure period, one field blank of each type was placed with the samples. Each 3-day sampling event included one 24-hour period when a canister sample was taken (i.e., September 22, September 28, and October 4, respectively). The total number of samples collected for Phase I was 27 unmodified and 27 modified OVMs.

Quality Assurance

As indicated above, an appropriate field blank (FB) was deployed for each triad of samples. An unmodified FB is an OVM whose outer plastic ring and windscreen have been removed and replaced with the analytical cap, making sure the ports on the cap and the cap itself are closed tightly. A modified FB is an OVM with the same modified diffusion path (using Teflon disks) and charcoal pad retainer as the modified samplers, but with the outer plastic ring and Teflon filter removed and replaced with the analytical cap. The field blanks are then positioned on the sampling stand similar to the field samples, and collected, handled, stored and analyzed with the corresponding samples. For comparison purposes, six additional unmodified FBs were left inside closed cans during the last two sampling events. In addition, a logistic error led to the deployment of nine extra regular unmodified FBs during the third sampling event. Therefore, a total of 33 FBs (24 unmodified and 9 modified) were utilized during Phase I.

Analysis

Extraction and analytical procedures have been described in detail (Chung et al., 1999, Mornadi and Stock, 2000). Analysis was performed using a HP 6890 Series GC with a 5973

MSD and EnviroQuant software. The column employed was a Restek (RTX -624, 60m 0.25mm ID with 1.4 μm thickness column (Restek Corp., Bellefonte, PA; catalog # 10969). All samples were analyzed in one analytical batch. Four laboratory blanks were utilized for this analysis. Lab blanks are OVMs removed from factory-sealed cans immediately prior to extraction and analysis. After every 20 samples, a duplicate analysis of the 20th sample was run, followed by a 1 $\mu\text{g}/\text{mL}$ standard and a solvent wash.

Comparison Method Data

Results of the canister samples are not yet available from the TNRCC. However, hourly concentrations of compounds measured by the on-site continuous GC were furnished by the TNRCC for all sampling dates. As indicated earlier, comparison data were available for the following: benzene, 1,3-butadiene, ethyl benzene, styrene, toluene, o-xylene, and m/p-xylene. Continuous GC results were unavailable for most of the first sampling event (9/21-9/24) because of equipment malfunction, so comparison concentrations were only calculated for the second and third sampling events. Hourly concentrations were averaged over the clock hours corresponding to each OVM sample set. Since the continuous GC results were in units of ppb C (carbon), they were first converted to molar ppb by dividing by the number of carbons in the compound, and then to $\mu\text{g}/\text{m}^3$, assuming a temperature of 25° C.

IV. Results

All OVM sample concentrations of 1,3-butadiene, chloroprene, and limonene were analytically nondetectable. Only one sample each of methylene chloride, chloroform and β -pinene were detectable. Results for the remaining 14 target compounds (13 peaks) are summarized in Table 1.

Detection limits for all compounds are presented in Table 2. The mass method detection limits, shown in the first column, are determined as described before (Chung et al., 1999; Morandi and Stock, 2000). For compounds present as measureable contaminants in extraction solvents or charcoal wafers, the mass MDL is determined from the analysis of blanks. Since there were no discernible differences in mass loadings among types of field blanks (i.e., modified vs. unmodified or FBs stored in cans vs. those placed alongside samples) nor between field and lab blanks, a total of 37 blanks (33 FBs and 4 LBs) were used to compute these MDLs. For compounds not present as contaminants, the mass MDL is determined from the standard deviation of multiple analyses of a low concentration standard. For this analysis, an accumulated database (n=90) of results from analyses of 0.1 $\mu\text{g}/\text{mL}$ standards was utilized. These mass MDLs are then used to calculate appropriate air concentration MDLs. The second column of Table 2 shows the analytical detection limits for the target compounds. These were determined from a recent experiment in which seven solutions for each of a series of low-concentration standards were analyzed. The analytical detection limit was determined from

the standard deviation of the seven analyses of the lowest concentration standard that yielded a relative standard deviation of $\leq 10\%$. Note that the units of μg and $\mu\text{g/mL}$ are equivalent in this table, since 1 mL of solvent is used to extract the OVM mass.

Table 3 shows the appropriate air concentration method detection limits (MDLs) for each of the three sample durations, for the unmodified OVMs. Assuming that the modified samplers have double the sampling rate of the unmodified ones, then the concentration MDLs for the modified OVMs would be one-half of the values shown in Table 3.

Determination of Optimal Sampling Duration

In the proposal for this research project, it was stated that an optimal sampling duration for the unmodified OVM would be determined as the shortest sampling duration for which at least 50% of the target compounds have at least 75% of measurements above the MDL. The numbers of sample concentrations above the MDL for each compound, for each triplicate sample set are presented in Table 4. All measurements were below the appropriate MDLs for seven compounds: 1,3-butadiene, methylene chloride, chloroprene, chloroform, β -pinene, d-limonene and naphthalene. All measurements were above the MDLs for seven compounds: MTBE, benzene, toluene, ethyl benzene, m/p-xylene (1 peak) and o-xylene. From the data in the table (and counting m/p-xylene as two compounds) it can be determined that the criterion for optimal sampling duration is satisfied by both the 2-day and 3-day samples. However, for four compounds with typical concentrations near the MDL the 3-day samples had more results $>$ MDL than did the 2-day samples (i.e., 7 vs. 6 for trichloroethylene, 3 vs. 0 for styrene, 6 vs. 2 for α -pinene, and 9 vs. 7 for p-dichlorobenzene)

Comparison of OVM Results with Continuous GC Measurements

In Table 5, mean concentrations for each triplicate set of OVMs are compared with the continuous GC measurements averaged over the corresponding periods, for the compounds measured by both. In general, good agreement between the results of the two methods was observed. For five of the six data sets, concentrations of butadiene and styrene were not analytically detectable by the OVMs, but the corresponding concentrations measured by the GC were all below the OVM MDLs. For the 3-day samples during the third sampling event, the concentrations of both these compounds as measured by the GC were somewhat above the MDLs, although the OVMs results were either nondetectable (butadiene) or less than half the GC concentration (styrene). For the remaining comparison compounds, the bias between results from the two methods is shown in Table 6. For benzene, ethyl benzene, o-xylene and m/p-xylene, the OVMs showed a small positive bias relative to the reference method, for 22 of 24 comparisons. The magnitude of the bias tended to decrease as the duration of the sample increased. For toluene, the OVMs showed a consistent negative bias relative to the GC, with no discernable decrease in magnitude with increasing duration. Agreement of the OVM results within $\pm 30\%$ of the continuous GC measurements is encouraging, especially

considering the dissimilarities of the methods and the fact that the accuracy and variability of this method is unknown. The clearly improved agreement observed for the 3-day samples (with the exception of toluene) may be due to decreased measurement error associated with the increased sample mass.

Comparison of Unmodified vs. Modified OVMs

From a visual examination of the data in Table 1, there appears to be good correlation between results for the modified and unmodified samplers, but the concentrations calculated for the modified OVMs show a consistent low bias relative to the original unmodified OVMs. Since the modified sampler concentrations were calculated on the theory-based assumption that the sampling rates are double those of the unmodified ones, this approach does not account for any significant deviations from theoretical predictions. In order to examine this issue further, regression analysis was performed for the modified/unmodified sample pairs using blank-corrected sample masses. The results are summarized in Table 7. Compounds whose concentrations are < MDL for all or almost all samples are excluded (i.e., butadiene, methylene chloride, chloroprene, chloroform, styrene, β -pinene, limonene and naphthalene). The large R^2 values indicate the expected good correlation between the OVM types. The values for the regression slopes (β), however, suggest that the assumed doubling of the sampling rate is not correct. Since the regression intercepts are all essentially zero, the slopes represent the modified/unmodified mass ratios. These ratios range from 1.61 to 1.88, with a mean of 1.75.

The modified samplers increased the number of measurements above the corresponding MDLs to one hundred percent for trichloroethylene with 3-day sampling, p-dichlorobenzene with 2-day or longer sampling, and α -pinene with 2-day or longer sampling.

V. Conclusions

The results from Phase I of this project indicate that OVMs can be successfully used to monitor ambient air for a number of air toxics. Comparison of OVM measurements with those from a continuous GC at the same site indicated good agreement. A consideration of the proportion of OVM samples > MDL, as well as the better agreement between the continuous GC measurements and OVM samples with greater mass, support the choice of 3 days as the optimal sampling duration for the remaining project phases. Comparison of results of the modified OVMs with those of the original unmodified samplers showed high correlation, but the observed average increase in sampling rate (75%) was somewhat less than the theoretically predicted doubling. The cause of this discrepancy is unknown, but further evaluation is warranted. Overall, these results reinforce the concept that the OVMs are a useful tool for performing the intensive temporal and spatial monitoring required in Phases 2 and 3.

Table1. Summary of OVM Sampling Results

TABLE 1. Summary of OVM Sampling Results (ug/m3)														
DATE START	DATE END	N	MTBE		Carbon tetrachloride		Benzene		Toluene/xylene		Totalene		Toluene	
			UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	
06/1/2001	06/02/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	20.25	17.27	0.84	0.77	2.8	2.35	6.45E-02	1.75E-02	0.37	0.27	0.34	0.34
		Median	1.26	1.34	0.11	4.50E-02	0.15	0.24	2.05E-02	3.25E-02	0.09	0.28	4.42E-02	0.27
		Mid-range	20.34	16.87	0.74	0.71	2.86	2.29	0.06	0.06	0.31	4.74	0.37	0.37
		Maximum	19.24	16.87	0.76	0.64	2.42	2.19	0.06	0.04	4.38	4.41	0.34	0.34
Minimum	21.54	16.96	0.96	0.73	2.86	2.84	0.04	0.13	0.53	5.77	0.44	0.44		
N														
06/02/2001	06/03/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	14.22	11.9	0.6	0.48	2.26	2.07	6.13E-02	0.88E-02	11.72	10.26	0.4	0.4
		Median	1.35	1.15	0.08E-02	4.27E-02	0.24	0.22	4.17E-02	2.38E-02	0.94	1.57	7.84E-02	0.34
		Mid-range	14.14	11.87	0.83	0.48	2.31	2.22	6.27E-02	6.13	11.52	10.31	0.34	0.34
		Maximum	12.82	11.87	0.52	0.43	2.34	1.89	0.11	0.06	10.68	9.46	0.34	0.34
Minimum	15.21	15.14	0.88	0.82	2.52	2.31	0.04	0.13	12.53	11.7	0.44	0.44		
N														
06/03/2001	06/04/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	11.24	8.17	0.54	0.47	2.43	1.81	6.75E-02	8.43E-02	4.34	7.01	0.33	0.33
		Median	0.7	0.43	3.06E-02	2.06E-02	0.5	0.44E-02	2.24E-02	3.44E-02	0.58	0.46	1.53E-02	0.33
		Mid-range	11.34	9.27	0.57	0.48	2.34	2.22	0.06	0.06	4.41	7.76	0.33	0.33
		Maximum	10.46	9.73	0.52	0.43	2.26	1.87	0.04	0.06	6.72	7.34	0.33	0.33
Minimum	12.31	9.82	0.57	0.47	2.96	2.34	0.06	0.07	4.97	8.33	0.33	0.33		
N														
06/04/2001	06/05/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	5.17	4.33	0.34	0.44	1.86	1.64	4.37E-02	5.44E-02	5.7	4.36	0.13	0.13
		Median	0.89	0.44	0.38	3.22E-02	0.41	0.11	6.24E-02	3.15E-02	1.76	0.24	0.2	0.2
		Mid-range	5.27	4.18	0.51	0.48	1.76	1.87	0.02	0.04	5.31	4.54	0.29	0.29
		Maximum	4.34	3.94	0	0.47	1.58	1.58	0	0.03	3.58	3.88	0	0
Minimum	6.11	4.89	0.66	0.53	2.32	1.89	0.12	0.04	7.04	4.33	0.27	0.27		
N														
06/05/2001	06/06/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	5.82	5.4	0.52	0.48	1.78	1.81	3.27E-02	3.71E-02	5.87	5.34	0.18	0.18
		Median	2.29	0.7	1.54E-02	1.15E-02	0.73	1.45E-02	4.74E-02	2.24E-02	0.97	0.71	4.54E-02	0.18
		Mid-range	5.81	5.45	0.51	0.44	2.13	1.81	0.02	0.03	5.58	5.32	0.14	0.14
		Maximum	5.74	5.29	0.51	0.48	2.38	1.89	0	0.02	4.47	5.24	0.14	0.14
Minimum	6.22	5.47	0.52	0.53	2.32	1.82	0.04	0.06	6.57	5.46	0.23	0.23		
N														
06/06/2001	06/07/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	5.41	4.88	0.48	0.42	1.86	1.71	2.84E-02	2.75E-02	4.36	4.38	0.17	0.17
		Median	2.23	0.13	2.50E-02	3.11E-02	0.71	6.00E-02	1.25E-02	4.07E-02	0.26	0.32	5.43E-02	0.17
		Mid-range	5.32	4.85	0.48	0.47	1.86	1.71	0.02	0.03	4.78	4.28	0.17	0.17
		Maximum	5.22	4.43	0.44	0.34	1.87	1.82	0.02	0.02	4.91	4.71	0.17	0.17
Minimum	5.87	4.88	0.51	0.45	2.27	1.75	0.04	0.03	5.17	4.72	0.18	0.18		
N														
06/07/2001	06/08/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	11.74	10.08	0.86	0.78	4.74	3.7	1.71E-02	1.77E-02	6.45	4.46	0.32	0.32
		Median	0.71	0.53	3.26E-02	2.08E-02	0.71	0.74	0.25	2.84E-02	0.57	1.48E-02	1.72E-02	0.32
		Mid-range	11.84	10.34	0.86	0.77	4.54	3.73	0.06	0.06	6.75	4.46	0.32	0.32
		Maximum	11.84	9.48	0.87	0.78	4.36	3.44	0.06	0.06	6.32	4.87	0.32	0.32
Minimum	11.95	10.47	0.82	0.83	4.41	3.89	0.17	0.13	6.75	5.22	0.34	0.34		
N														
06/08/2001	06/09/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	10.41	9.38	0.81	0.83	3.21	2.46	0.72	0.7	6.97	4.86	0.2	0.2
		Median	0.16	0.33	2.41E-02	3.69E-02	0.1	0.12	1.64E-02	1.62E-02	0.57	0.26	2.37E-02	0.2
		Mid-range	10.86	9.46	0.86	0.87	3.26	2.81	0.11	0.13	5.86	4.74	0.27	0.27
		Maximum	10.78	9.87	0.82	0.87	3.38	2.82	0.11	0.04	4.46	4.41	0.18	0.18
Minimum	11.27	9.87	0.86	0.88	3.28	3.05	0.14	0.17	5.46	4.42	0.22	0.22		
N														
06/09/2001	06/10/2001	Mean	3	3	3	3	3	3	3	3	3	3	3	3
		1st Deviation	12.32	10.78	0.57	0.48	3.42	3.23	6.64E-02	0.12	5.26	4.46	0.17	0.17
		Median	0.74	0.75	4.74E-02	3.62E-02	0.24	0.26	2.48E-02	1.83E-02	0.58	0.22	3.87E-02	0.17
		Mid-range	11.47	10.34	0.54	0.48	3.34	3.11	0.04	0.12	5.75	4.86	0.15	0.15
		Maximum	11.82	10.27	0.54	0.45	3.24	3.05	0.07	0.17	4.92	4.72	0.15	0.15
Minimum	12.18	11.83	0.62	0.62	3.76	3.52	0.12	0.14	6.84	5.29	0.27	0.27		

Table1. Summary of OVM Sampling Results (continued)

TABLE 1. Summary of OVM Sampling Results (ug/m3)															
ethane	Ethyl benzene		m-Xylene		o-Xylene		Styrene		p-Xylene		p-Dichlorobenzene		Toluene		
	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	UNMODIFIED	MODIFIED	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.33	0.92	0.98	4.85	4.26	2.37	2.05	0	0	0.38	0.34	0.25	0.24	0.13	0.03	
1.03E-02	7.32E-02	4.94E-02	0.55	0.35	0.25	0.12	0	0	4.78E-02	3.06E-02	0.24	4.26E-02	7.32E-02	0.03E-02	
0.33	0.95	0.98	4.85	4.40	2.32	2.06	0	0	0.38	0.30	0.25	0.25	0.11	0.04	
0.35	0.94	0.98	3.99	3.80	2.60	1.91	0	0	0.34	0.31	0	0	0.13	0.04	
0.34	0.93	0.96	0.53	4.57	2.55	2.14	0	0	0.43	0.31	0.46	0.35	0.14	0.10	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.30	0.93	0.97	3.99	3.30	1.9	1.42	0	0	0.4	0.35	0.16	0.25	0.44E-02	0.10E-02	
4.53E-02	0.11	0.1	0.23	0.37	4.23E-02	0.18	0	0	7.87E-02	4.74E-02	0.16	1.34E-02	1.36E-02	2.47E-02	
0.34	0.97	0.18	3.0	3.19	1.63	1.35	0	0	0.34	0.33	0.22	0.22	0.00	0.04	
0.32	0.75	0.72	3.43	3.04	1.49	1.31	0	0	0.33	0.32	0	0.2	0.02	0.04	
0.43	0.97	0.92	3.84	3.14	1.67	1.61	0	0	0.49	0.41	0.32	0.25	0.13	0.07	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.35	0.93	0.72	3.57	2.94	1.4	1.17	0	0	0.30	0.21	0.2	0.25	0.32E-02	0.30E-02	
1.03E-02	7.77E-02	1.07E-02	0.15	0.15	7.30E-02	3.03E-02	0	0	1.06E-02	1.02E-02	0.21E-02	1.22E-02	0.58E-02	4.90E-02	
0.35	0.95	0.75	3.29	2.86	1.38	1.18	0	0	0.37	0.32	0.32	0.22	0.00	0.05	
0.36	0.14	0.73	3.22	2.71	1.34	1.12	0	0	0.36	0.26	0.24	0.21	0.00	0.05	
0.32	0.89	0.14	3.51	2.91	1.49	1.19	0	0	0.34	0.32	0.32	0.24	0.02	0.05	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.17	1.19	0.97	3.72	3	1.3	1.00	0	0	0.3	0.25	0.40	0.32	7.07E-02	7.98E-02	
1.03E-02	0.24	7.36E-02	0.94	0.24	0.36	0.91E-02	0	0	6.48E-02	1.26E-02	0.26	0.12	0.66E-02	0.27E-02	
0.17	1.15	0.98	3.57	2.86	1.25	1.00	0	0	0.29	0.25	0.42	0.29	0.11	0.04	
0.18	0.82	0.93	3.07	2.77	1.60	0.94	0	0	0.34	0.21	0.34	0.16	0	0.07	
0.18	1.43	0.96	4.72	3.25	1.69	1.11	0	0	0.37	0.25	0.40	0.41	0.13	0.04	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.14	1.19	1.18	3.87	3.48	1.25	1.18	0	0	0.29	0.25	0.36	0.41	4.25E-02	7.09E-02	
4.32E-02	0.18	4.34E-02	0.33	0.02E-02	7.25E-02	2.61E-02	0	0	3.46E-02	1.26E-02	0.16	2.96E-02	7.82E-02	1.13E-02	
0.15	1.02	1.03	3.53	3.49	1.23	1.17	0	0	0.29	0.25	0.40	0.40	0.00	0.07	
0.13	0.93	1.07	3.47	3.41	1.25	1.18	0	0	0.29	0.25	0.42	0.44	0.00	0.07	
0.15	1.29	1.00	4.03	3.33	1.23	1.21	0	0	0.32	0.25	0.27	0.48	0.13	0.07	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.18	0.93	0.97	3.25	2.97	1.14	0.96	0	0	0.35	0.25	0.42	0.26	7.26E-02	0.27E-02	
4.43E-02	4.43E-02	0.94E-02	0.11	0.13	0.18E-02	4.01E-02	0	0	3.08E-02	1.24E-02	7.42E-02	1.06E-02	3.11E-02	2.47E-02	
0.18	0.97	0.98	3.17	2.82	1.11	0.97	0	0	0.29	0.24	0.40	0.40	0.07	0.05	
0.15	0.94	0.93	3.12	2.73	1.10	0.96	0	0	0.29	0.24	0.36	0.31	0.07	0.05	
0.18	1.03	0.94	3.34	2.90	1.21	1.04	0	0	0.35	0.26	0.50	0.40	0.07	0.04	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.22	1.19	1.05	3.97	3.40	1.3	1.24	0	0	0.30	0.26	0.31	0.44	4.48E-02	0.48E-02	
2.66E-02	0.12	4.94E-02	0.18	0.11	1.96E-02	4.77E-02	0	0	9.27E-02	2.79E-02	0.11	3.06E-02	0.41E-02	4.94E-02	
0.25	1.18	1.07	3.83	3.31	1.41	1.27	0	0	0.35	0.24	0.32	0.40	0.12	0.04	
0.25	1.07	0.96	3.79	3.33	1.38	1.19	0	0	0.30	0.24	0.36	0.41	0	0	
0.26	1.35	1.00	4.11	3.33	1.41	1.27	0	0	0.49	0.26	0.40	0.40	0.18	0.04	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.17	1.18	0.94	3.94	3.26	1.35	1.17	0	0	0.48E-02	0.27	0.16	0.4	0.34	0.15	
1.03E-02	4.29E-02	0.34E-02	0.13	0.12	0.71E-02	7.19E-02	0	0	4.49E-02	3.17E-02	7.16E-02	4.92E-02	4.96E-02	3.41E-02	
0.17	1.05	0.96	3.89	3.31	1.37	1.25	0	0	0.32	0.19	0.36	0.32	0.11	0.07	
0.18	1.02	0.93	3.89	3.14	1.29	1.08	0	0	0.32	0.19	0.32	0.31	0.13	0.04	
0.18	1.17	1.03	3.79	3.36	1.45	1.23	0	0	0.18	0.22	0.20	0.31	0.45	0.11	
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
0.17	1.19	1.03	3.97	3.71	1.38	1.27	0.32	0.34	0.2	0.18	0.32	0.27	0.03E-02	0.47E-02	
1.03E-02	0.11	0.16E-02	0.38	0.23	0.15	0.13E-02	0.1	4.56E-02	3.71E-02	1.46E-02	4.91E-02	4.91E-02	1.82E-02	0.06E-02	
0.17	1.10	1.03	3.82	3.94	1.38	1.28	0.37	0.34	0.25	0.18	0.34	0.27	0.00	0.07	
0.15	0.98	0.94	3.84	3.33	1.25	1.14	0.26	0.26	0.19	0.17	0.25	0.25	0.07	0.04	
0.19	1.23	1.17	4.43	3.97	1.54	1.36	0.44	0.38	0.25	0.27	0.42	0.32	0.11	0.07	

Table 2. Target Compound Detection Limits: Mass Method Detection Limits (MDL) and Analytical Detection Limits (ADL)

VOC	MDL (µg/mL)	ADL (µg/mL)
1,3-Butadiene	0.13	0.04
Methylene chloride	0.02	0.08
MTBE	0.02	0.01
Chloroprene	0.02	0.02
Chloroform	0.02	0.01
Carbon tetrachloride	0.03	0.01
Benzene	0.01	0.01
Trichloroethylene	0.01	0.01
Toluene	0.07	0.01
Tetrachloroethylene	0.01	0.01
Ethyl benzene	0.01	<0.01
m/p-Xylene	0.02	<0.01
o-Xylene	0.01	<0.01
Styrene	0.02	0.01
α-Pinene	0.03	0.01
β-Pinene	0.02	0.01
d-Limonene	0.02	0.01
p-Dichlorobenzene	0.02	0.01
Naphthalene	0.06	0.01

Table 3. Method Detection Limits for Different Sampling Durations (µg/m³)

Compound	24 Hours	48 Hours	72 Hours
1,3-Butadiene	3.81	1.90	1.27
Methylene chloride	0.36	0.18	0.12
MTBE	0.32	0.16	0.11
Chloroprene	0.68	0.32	0.23
Chloroform	0.45	0.23	0.15
Carbon tetrachloride	0.74	0.37	0.25
Benzene	0.22	0.12	0.07
Trichloroethylene	0.20	0.10	0.07
Toluene	1.56	0.78	0.52
Tetrachloroethylene	0.28	0.14	0.09
Ethyl benzene	0.33	0.16	0.11
m/p-Xylene	0.50	0.25	0.17
o-Xylene	0.20	0.10	0.07
Styrene	0.78	0.39	0.26
α-Pinene	0.85	0.43	0.29
β-Pinene	0.62	0.31	0.21
d-Limonene	0.74	0.37	0.25
p-Dichlorobenzene	0.62	0.31	0.21
Naphthalene	1.56	0.78	0.52

**Table 4. Number of Unmodified OVM Samples with Concentrations > MDL
by Sample Triad**

Compound	Period 9/21-9/24			Period 9/26-9/29			Period 10/2-10/5		
	1 d	2 d	3 d	1 d	2 d	3 d	1 d	2 d	3 d
1,3-Butadiene	0	0	0	0	0	0	0	0	0
Methylene chloride	0	0	0	0	0	0	0	0	0
MTBE	3	3	3	3	3	3	3	3	3
Chloroprene	0	0	0	0	0	0	0	0	0
Chloroform	0	0	0	0	0	0	0	0	0
Carbon tetrachloride	3	3	3	0	3	3	3	3	3
Benzene	3	3	3	3	3	3	3	3	3
Trichloroethylene	0	0	2	0	0	0	0	3	3
Toluene	3	3	3	3	3	3	3	3	3
Tetrachloroethylene	3	3	3	2	3	3	3	3	3
Ethyl benzene	3	3	3	3	3	3	3	3	3
m/p-Xylene	3	3	3	3	3	3	3	3	3
o-Xylene	3	3	3	3	3	3	3	3	3
Styrene	0	0	0	0	0	0	0	0	2
α-Pinene	0	1	3	0	0	3	0	0	0
β-Pinene	0	0	0	0	0	0	0	0	0
d-Limonene	0	0	0	0	0	0	0	0	0
p-Dichlorobenzene	0	1	3	1	3	3	0	3	3
Naphthalene	0	0	0	0	0	0	0	0	0

Table 5. Comparison of Results of OVM vs. Continuous GC Measurements (µg/m³)

Sampling Period	1,3-Butadiene		Benzene		Ethyl benzene		o-Xylene		m/p-Xylene		Styrene		Toluene	
	GC	OVM	GC	OVM	GC	OVM	GC	OVM	GC	OVM	GC	OVM	GC	OVM
1 day (2)	0.66	ND	1.80	1.86	0.97	1.09	1.08	1.30	3.37	3.72	0.04	ND	6.33	5.30
1 day (3)	0.75	ND	3.12	4.16	0.96	1.18	1.11	1.40	3.41	3.91	0.27	ND	6.64	6.41
2 days (2)	0.73	ND	2.08	2.18	0.99	1.09	1.10	1.25	3.46	3.67	0.08	ND	7.97	5.87
2 days (3)	0.60	ND	2.83	3.21	0.88	1.06	1.08	1.35	3.38	3.64	0.20	ND	6.35	5.51
3 days (2)	0.67	ND	2.00	1.95	0.92	0.98	1.03	1.14	3.17	3.21	0.07	ND	6.91	4.85
3 days (3)	1.41	ND	3.35	3.43	1.06	1.09	1.31	1.38	4.00	3.97	0.75	0.32	6.77	5.25

(2): Second sampling event (9/26-29)

(3): Third sampling event (10/02-05)

ND: not detected

Table 6. Bias^a of OVM Measurements Relative to Continuous GC Measurements (%)

Sampling Period	Benzene	Ethyl benzene	o-Xylene	m/p-Xylene	Toluene
1 day (2)	3.41	12.83	19.73	10.38	-16.30
1 day (3)	33.32	22.54	26.21	14.85	-3.47
2 days (2)	4.89	9.83	13.73	6.19	-26.37
2 days (3)	13.23	20.50	25.28	7.73	-13.24
3 days (2)	-2.50	6.25	11.22	1.03	-29.77
3 days (3)	2.25	3.35	4.85	-0.69	-22.36

^a Bias = (OVM-GC)/GC x 100

(2): Second sampling event (9/26-29)

(3): Third sampling event (10/02-05)

**Table 7. Regression Parameters for the Relationship Between Modified and Unmodified
OVM Masses**

VOC	β (slope)	P β	B (intercept)	p B	R ²
MTBE	1.68	0.000	0.01	0.413	0.99
Carbon tetrachloride	1.58	0.000	0.00	0.235	0.97
Benzene	1.88	0.000	-0.01	0.644	0.98
Trichloroethylene	1.76	0.003	0.00	0.218	0.79
Toluene	1.73	0.000	0.03	0.532	0.98
Tetrachloroethylene	1.73	0.000	0.00	0.982	0.98
Ethyl benzene	1.85	0.000	0.00	0.756	0.98
m/p-Xylene	1.85	0.000	-0.00	0.901	0.94
o-Xylene	1.76	0.000	0.00	0.713	0.98
α -Pinene	1.61	0.000	0.00	0.252	0.98
p-Dichlorobenzene	1.85	0.000	-0.00	0.901	0.94

Ambient Air Toxics in the Houston-Galveston Area with High and Low TRI Emissions – A Pilot Study of Temporal and Spatial Concentrations Using Passive Sampling Devices (PSDs)

Phase II and Phase III

Temporal and Spatial Passive Air Toxics Monitoring at Selected Passive Air Monitoring Sites

I. Introduction

This report covers activities performed under Phases 2 and 3 of a multiple-Phase research project intended to evaluate and demonstrate the utility of employing passive (diffusive) air samplers to investigate the temporal and spatial variability of ambient air concentrations of selected air toxics in the Houston-Galveston area. The results of Phase I indicated that the 3M 3500 Organic Vapor Monitor (OVM) could be successfully used to monitor short-term ambient air concentrations of a number of volatile organic compounds (VOCs). A sampling duration of 72 hours (3 days) was determined to be optimal. Comparison of OVM measurements with those from a continuous gas chromatograph (GC) at the same site indicated good agreement. A comparison of a modification of the OVM (diffusion path halved) with the original OVM indicated high correlation of measurements, but with an increased sampling rate somewhat less than that theoretically predicted.

The objective of Phase II was to collect a series of 72-hour OVM samples over the period of a year at two central air monitoring stations and, simultaneously, at the centroids of the census tracts in which each of the monitoring stations was located. The planned sampling frequency was every 12 days, which would include a routine 24-hour canister sampling, performed every 6 days by the Texas Commission on Environmental Quality (TCEQ). Although the differences in sampling duration between the OVMs (3 days) and canisters (1 day) prevent a sample-by-sample comparison, some comparison of long-term average concentrations would be feasible. Furthermore, a continuous GC at one of the monitoring stations should allow a direct comparison of this method with the OVMs for some common target compounds.

The purpose of Phase III was to perform a more intensive spatial monitoring in the areas surrounding three central monitoring stations. During each of six sampling events, OVMs were deployed outside ten residences in each area, within a 2-mile radius of the central site. The planned sampling frequency was every 24 days, over approximately 4 months. Both

Phases 2 and 3 were intended to provide important information regarding the representativeness of central site monitoring for VOCs.

Since TCEQ canister and continuous GC results were available only up through March 2003, comparisons with these methods will not be discussed in this report. Likewise, the results of a supplemental project comparing the results of duplicate 72-hour canister samples (prepared and analyzed by EPA Region 6 laboratory) with collocated duplicate OVM samples at the Clinton monitoring station will be reported later.

II. Target Compounds and Sampling Sites

During Phase I there were 19 target VOCs which were quantified in the samples. For Phases 2 and 3, additional compounds identified from chromatographs of outdoor samples were included as analytes, for a current total of 31 VOCs. These are shown in Table 1, in order of elution from the GC column. The original 19 target compounds are indicated with an asterisk. The original list of compounds has been used for the current interlaboratory comparison of split extracts, described in the cover report.

Three continuous air monitoring stations (CAMS) operated by the TCEQ were utilized for Phases 2 and 3: Aldine (C8/C108/C150), Clinton (C403/C113/C304) and Deer Park #2 (C35/C139/C1001). A Houston regional map showing the relative locations of these monitoring sites, along with local maps of the areas around each site, are given in Appendix B. The Aldine site is located 10 mi. north of downtown Houston; the Clinton site is 6.5 mi. east of downtown, just north of the Houston Ship Channel; and the Deer Park site is 15 mi. ESE of downtown. The Aldine area is considered an area with relatively few major point sources of air toxics; there are only 8 Toxics Release Inventory (TRI) sites within 6 mi. of the monitoring station, and none within 2 mi. In contrast, the Clinton and Deer Park areas have relatively large numbers of major point sources, many of which are petrochemical facilities. There are 77 TRI sites within 6 mi. of the Clinton monitoring station, and 69 TRI sites within the same distance of the Deer Park monitoring station. However these areas differ in the number of major sources in close proximity to the monitoring stations, i.e., 10 TRI sites within 2 mi. of the Clinton site, and none within 2 mi. of the Deer Park site. Only the Aldine and Clinton sites were employed for Phase II sampling. All three sites were utilized for Phase III sampling. The predominant wind direction at all three monitoring locations is from the southeast.

III. Methods

Sampling

There were 27 total 72-hour sampling events during Phases 2 and 3, which are summarized in Table 2. Several scheduled samplings during Fall 2002 were not attempted due to adverse weather conditions (very heavy rainstorms). For each Phase II sampling event, 2 or more OVMs (at least one sample and one field blank) were placed on the roof of the sampling trailer at each of the two TCEQ monitoring sites (Aldine and Clinton). These passive samplers were attached to an all-metal sampling stand with a wire-mesh tray placed near the top (five feet above the roof), and an aluminum foil-covered top cover to protect the samplers from rain and direct sunlight. The OVMs were suspended from the wire-mesh tray, at least six inches below the top cover. Flow of air was unrestricted from all sides. An additional OVM sample was placed near the centroid of the census tract in which each of the monitoring stations was located.

For each of the six Phase III sampling events, an additional 10 (Aldine) or 11 (Clinton) OVMS were deployed outside the homes of volunteer study participants, located within a 2-mile radius of the central monitoring station (MS). Also, during each Phase III sampling event, simultaneous measurements were performed at the Deer Park MS, the corresponding centroid, and outside 10 homes within 2 miles of the Deer Park MS. Duplicate samplers were placed at half of the homes in each of the three areas. The home samplers were usually placed under a carport or porch roof or the house eaves to provide protection from rain and direct sunlight.

Placement of samplers at the centroid locations presented some special challenges. Logistic and security considerations prevented placement of the OVMs at the exact position of the centroid. In the Aldine area, three different locations were used for centroid sample placement, two fences at an elementary school, a fence surrounding a business facility, and a sign by the side of a road. As described in the Second Phase II Progress Report (April 24, 2003), several OVMs were missing or showed signs of tampering upon retrieval, during the first 8 sampling events, causing the location changes. The same location (sign by the road) was used for the final 19 sampling events. All of the sites used for centroid samples in Aldine were in the same general area, and were located within approximately 0.25 mi. of the true centroid. The final placement on the sign was next to a road with light to medium density local traffic. In the Clinton area, the same site was used for all centroid samples, but it was 0.5 mi. from the true centroid, which was located in an inaccessible area, a landfill. The centroid sample was placed on a fence surrounding a pasture near the end of a dead-end street leading to the landfill. Since there were no houses on this street, it was presumed that traffic was minimal. In the Deer Park area, the site of the centroid sample was only approximately 600 ft. from the true centroid. The OVM was attached to a stop sign at the intersection of two neighborhood streets with presumably light traffic. At all centroid sites in the three areas, the samplers were not protected from the elements, but the OVMs were always placed with the diffusive face (windscreen) side facing down, to avoid the direct impact of rain.

All OVMs were obtained directly from 3M, without labels affixed to the badges. The first 17

sampling events were conducted with one lot of OVMS. A second lot, from a new production facility in Canada, was employed for the remaining samplings.

Mapping

All sampling locations (monitoring stations, centroids and houses) were recorded using a Garmin eTrex Legend handheld Global Positioning System (GPS) unit (Garmin International, Inc., Olathe, KS). All positions were downloaded to a personal computer and mapped with Mapsource MetroGuide U.S.A., v. 5 (Garmin). Distances and directions of locations were determined with the software.

Analysis

At the end of each sampling period all OVMS were retrieved, capped and stored under refrigeration until analysis, which was typically within one week of retrieval. Analysis was performed using a HP 6890 Series GC with a 5973 MSD and EnviroQuant software. The column employed was a Restek (RTX -624, 60m 0.25mm ID with 1.4 um thickness column (Restek Corp., Bellefonte, PA; catalog # 10969). Samples were analyzed in 28 analytical batches. Most Phase II analyses consisted of only 7 OVMS (4 samples, 2 field blanks and 1 lab blank). Batches of approximately 55 OVMS were analyzed on the 6 runs that included Phase III samples.

Quality Assurance

As indicated above, a field blank (FB) was deployed at each central monitoring station during each sampling event. A FB is an OVMS whose outer plastic ring and windscreen have been removed and replaced with the analytical cap, making sure the ports on the cap and the cap itself are closed tightly. The FB is then positioned on the sampling stand near the field sample(s), and collected, handled, stored and analyzed with the corresponding samples. At least one laboratory blank (LB) was analyzed in each analytical batch. Lab blanks are OVMS removed from factory-sealed cans immediately prior to extraction and analysis. A total of 60 FBs and 33 LBs were analyzed. Mean blank values were subtracted from all sample masses.

Field duplicate samples were collected at half the homes during Phase III sampling and at the Clinton MS during most of the 2003 sampling events. A total of 115 duplicate sample pairs were analyzed.

In order to investigate any impact of the differences in sampling heights (trailer roof top at monitoring stations vs. ground level elsewhere), paired samples were collected during 10 sampling events at the Clinton MS. One of each pair was placed in the usual position on top of the trailer, and the other was placed under a protective roof within a secure fenced-in area

near the trailer, at ground level (OVMs placed approximately 6 ft. above the ground, similar to placement at the homes and centroids).

For the larger analytical batches resulting from Phase III sampling events, after every 20 samples, a duplicate analysis of the 20th sample was run, followed by a 1 ug/mL standard (calibration check) and a solvent wash. A total of 18 duplicate analyses and 18 calibration checks were run.

Calculations and Data Analysis

All calculations of air concentrations, analyses of data, statistical tests, and graphs were produced using SPSS for Windows, v. 11.5 (SPSS, Inc., Chicago, IL). Statistical significance was defined as $p < 0.05$.

IV. Results

All OVM sample concentrations of 1,3-butadiene, isoprene and chloroprene were analytically nondetectable, thus reducing the target list to 28 VOCs. Target compounds with a relatively large proportion of nondetectable samples (approximately half or more) include the following 7 VOCs: methylene chloride, methyl ethyl ketone, 2,3-dimethylpentane, n-nonane, styrene, β -pinene, and naphthalene. Results for these compounds will not generally be presented, except as boxplots.

Detection limits for the 28 target compounds are presented in Table 3. The mass method detection limits (MDLs), shown in the first two data columns, are determined as described previously (Chung et al., 1999; Morandi and Stock, 2000). For compounds present as measureable contaminants in extraction solvents or charcoal wafers, the mass MDL is determined from the analysis of blanks.

As mentioned previously, there were two production lots of OVMS employed in the sampling. During mid-June 2003, OVMS from the older lot (Lot 1) were depleted, and OVMS from a new lot (Lot 2) began to be used. Lot 2 was produced at a new 3M production facility in Canada, and analysis of blanks indicated some significant changes in background contaminant levels for some compounds. Therefore, MDLs were calculated separately for each lot, as shown in Table 3. Since there were no statistically significant differences in mass loadings between field and lab blanks within each lot, these two types of blanks were combined for the determination of the MDLs. For Lot 1, 54 blanks (36 FBs and 18 LBs) were used; for Lot 2, 39 blanks (24 FBs and 15 LBs) were employed.

For compounds not present as contaminants, the mass MDL is determined from the standard deviation of multiple analyses of a low concentration standard. For this determination, the accumulated results from the analyses of the 0.1 µg/mL standards from the 28 analytical batches were utilized. The mass MDLs calculated from either approach were then used to calculate 72-hour air concentration MDLs, which are presented in the third and fourth data columns of Table 3.

The fifth data column of Table 3 shows the 72-hour air concentration analytical detection limits (ADLs) for the target compounds. These were determined from an experiment in which seven solutions for each of a series of low-concentration standards were analyzed. The mass ADL was determined from the standard deviation of the seven analyses of the lowest concentration standard that yielded a relative standard deviation of $\leq 10\%$. The mass ADL for all 28 target VOCs but one was 0.01 µg/mL; for methylene chloride it was 0.08 µg/mL. Note that the units of µg and µg/mL are equivalent in this table, since 1 mL of solvent is used to extract the OVM mass.

For statistical analysis and plots, all measurements below the ADL were replaced by one-half the ADL. Measurements greater than the ADL but less than the MDL were included because, although the measurements are increasingly uncertain as values fall below the MDL, these estimates are considered better than any substitute value.

Quality Assurance

As an estimate of analytical precision, differences between the pairs of measurements on the 18 analytical duplicates were computed as percent relative differences, defined as the absolute difference between the pairs, divided by the mean of the pairs, expressed as a percentage. These results are shown in Table 4. Medians as well as means are presented, since histograms indicated this metric was not normally distributed for many compounds. Median relative differences were less than 10% for 16 of the 20 compounds, and less than 20% for the remaining 4.

The results of the 18 calibration check measurements of the 1.0 µg/mL standards are summarized in Table 5. Mean values are within 10 % of nominal, and standard deviations are approximately 10% or less for all compounds except MTBE and butadiene.

In order to estimate overall sampling/analytical precision, the same metric as used for the analytical duplicates was calculated for the 115 duplicate OVM sample pairs. Means and medians of the percent relative differences are presented in Table 6. Median relative differences ranged from 5 to 33%, with the highest values associated with target compounds with typically low collected masses. It should be pointed out that, while the paired OVMs were typically collocated within one meter of each other, and thus would be expected to

sample the same air mass, there may have been some situations (especially at the homes) where a close-by source (e.g., idling engine in a carport) may have differentially impacted the two samplers.

Analysis of the 10 paired samples collected at roof level and ground level at the Clinton MS showed no evidence of an effect of elevation on target VOC concentrations. The measurements were generally highly correlated, and a nonparametric test of difference between the pairs (Wilcoxon Signed Ranks Test) indicated that there were no significant differences in concentrations for any compound.

Phase II

A statistical summary of all Phase II samples by sampling location is presented in Table 7. Corresponding box plots of the concentration distributions for all compounds by sampling location are shown in Appendix C. It is clear, especially from the box plots, that there are discernible differences in measured concentrations of many target compounds between sampling sites. The median concentration for many compounds is highest at the Clinton MS. This is not surprising, considering that this site may be influenced by industrial emissions, barge and railroad traffic, and high-density automotive traffic. In order to determine whether the concentrations measured at the monitoring station were significantly different than those measured at the centroid in each of the two areas, the nonparametric Wilcoxon Signed Ranks Test was employed. For the Aldine area, 25 matched samples were available; for Clinton, 26 sample pairs were utilized. The results of these tests are summarized in Table 8.

From Table 8, it is clear that many of the target VOCs show significant differences between the central monitoring station and the centroid, but the pattern of differences in each area is distinctive. In Aldine, 11 of the 21 compounds are significantly higher at the centroid than at the MS; only one compound (chloroform) shows a significant difference in the opposite direction. In the Clinton area, the concentrations measured at the MS are significantly higher than those measured at the centroid for 13 of the 21 VOCs; only α -pinene and d-limonene are significantly higher at the centroid. In both areas the compounds exhibiting significant differences between locations are components of automotive emissions (exhaust and/or evaporative). Many of these may also be emitted by petrochemical facilities. It should be noted that none of the chlorinated compounds, nor other VOCs which are not emitted by mobile sources (pinene and limonene), show these dominant patterns of differences.

The Aldine monitoring station is situated on the grounds of a middle school, at a considerable distance from Aldine Mail Route, a medium to high density road, with much less truck traffic than Clinton Drive. Other than vehicular traffic, there appear to be no major sources of VOC emissions influencing this site. The Aldine centroid site is near medium-density neighborhood traffic. Taking into account both proximity and density of vehicular traffic, it would be

expected that the centroid site would be more influenced by automotive emissions than the monitoring station, although the intersite differences should not be as large as for the Clinton area.

The Clinton monitoring station is situated close to Clinton Drive, a road with relatively high traffic, especially large diesel trucks. Monitored concentrations may also be influenced by emissions from Houston Ship Channel petrochemical facilities and nearby railroad and barge traffic. The Clinton centroid site is at the end of a small neighborhood road, not in proximity to high or medium density traffic. The observation of relatively elevated levels of the terpene compounds (pinene and limonene) is consistent with the greater proximity of trees and dense vegetation at the centroid site.

Phase III

The results of the intensive spatial monitoring performed in Phase III are presented as box plots in Appendix D. These plots compare the concentration distributions at all houses, the centroid and the central monitoring station, for each of the three study areas. It is immediately clear from these plots that measurements at the MS are not necessarily representative of the outdoor concentrations at all locations in the area. This result may have important implications, since the central site is designed, and usually assumed, to be representative of a wide geographic area. However, local sources of air toxics, such as neighborhood automotive emissions and use of consumer products, may significantly impact various locations in the area.

The box plots for the Aldine area show that concentrations of many of the target VOCs are elevated outside many homes, relative to the MS. House 7 had the highest concentrations for 20 of the 28 compounds. Most, but not all of the compounds with elevated concentrations at this house are found in automotive emissions. This house (and others) illustrates the utility of measuring compounds such as methylene chloride, styrene and naphthalene, which are not usually found at detectable levels. House 3 had the highest concentrations of chloroform, and relatively elevated levels for most compounds.

The Clinton area box plots indicate that, although the Clinton MS tended to have the highest concentrations out of the four Phase II monitoring locations, measured levels outside homes in the Clinton area frequently exceeded measurements at the MS. Concentrations of 11 target VOCs were highest outside Clinton area House 10. Again, these compounds are those found in automotive emissions. Several other Clinton homes had elevated levels of specific compounds. The highest concentrations of methylene chloride and limonene were measured at House 2. House 6 had much higher outdoor levels of p-dichlorobenzene than any other location. Concentrations of naphthalene were elevated at House 5. The sources contributing to these localized increases in concentrations are unknown, but are likely to be consumer

products.

The box plots for the Deer Park area do not suggest any consistently elevated levels of target VOCs outside any of the homes. The ambient concentrations in Deer Park are generally lower than the other two areas, and appear more spatially homogeneous.

V. Conclusions

The overall conclusion from Phases 1, 2 and 3 of this project is that passive air sampling using OVMs is a uniquely useful tool for investigating spatial variation in ambient air concentrations of VOCs. This small, lightweight, unobtrusive and powerless device can be used to monitor community environments not easily accessible with standard monitoring techniques.

Specific Conclusions from Phase II

1. Statistically significant differences between concentrations measured at a monitoring station and at the centroid of the monitoring station's census tract were found for a number of target VOCs in two different areas.
2. In the Clinton area, the monitoring station overpredicted concentrations of thirteen compounds at the centroid site. In the Aldine area, the monitoring station underpredicted concentrations of eleven compounds at the centroid site.
3. The observed intersite concentration differences were consistent with the presumptive differential impact of automotive emissions at each site.

Specific Conclusions from Phase III

1. Passive air samplers can be used to measure differences in ambient concentrations within a relatively small geographic area.
2. Ambient measurements of VOCs at central monitoring stations are not generally representative of locations within a 2-mile radius.
3. Local sources of VOCs, presumably nearby automotive emissions and the use of consumer products, may produce elevated concentrations outside homes.

Table 1. Current List of Target Compounds

VOC	Original Target	CAS #
1,3-Butadiene	*	106-99-0
n-Pentane		109-66-0
Isoprene		78-79-5
Methylene chloride	*	75-09-2
MTBE	*	1634-04-4
n-Hexane		110-54-3
Chloroprene	*	126-99-8
Methylcyclopentane		96-37-7
Methyl ethyl ketone		78-93-3
Chloroform	*	67-66-3
2,3-Dimethylpentane		565-59-3
Carbon tetrachloride	*	56-23-5
Benzene	*	17-43-2
Trichloroethylene	*	79-01-6
Toluene	*	108-88-3
Tetrachloroethylene	*	1271-81-4
Ethyl benzene	*	1004-14-4
n-Nonane		111-84-2
m&p-Xylenes	*	108-38-3; 106-42-3
o-Xylene	*	95-47-6
Styrene	*	100-42-5
α -Pinene	*	80-56-8
n-Decane		124-18-5
1,3,5-Trimethylbenzene		108-67-8
1-Ethyl-2-methyl benzene		611-14-3
β -Pinene	*	127-91-3
1,2,4-Trimethylbenzene		95-63-6
d-Limonene	*	5989-27-5
1,2,3-Trimethylbenzene		526-73-8
p-Dichlorobenzene	*	106-46-7
Naphthalene	*	91-20-3

Table 2. Summary of Phases 2 and 3 Sampling Events

Sampling Event	Sampling Dates	Phase
1	09/16/02 – 09/19/02	2
2	09/27/02 – 09/30/02	2
3	10/10/02 – 10/13/02	2
4	11/27/02 – 11/30/02	2
5	12/14/02 – 12/17/02	2
6	01/14/03 – 01/17/03	2
7	01/27/03 – 01/30/03	2
8	02/12/03 – 02/15/03	2
9	02/25/03 – 02/28/03	2
10	03/08/03 – 03/11/03	2
11	03/21/03 – 03/24/03	2
12	04/01/03 – 04/04/03	2
13	04/14/03 – 04/17/03	2
14	04/25/03 – 04/28/03	2
15	05/07/03 – 05/10/03	2
16	05/20/03 – 05/23/03	2 and 3
17	05/31/03 – 06/03/03	2
18	06/13/03 – 06/16/03	2 and 3
19	06/24/03 – 06/27/03	2
20	07/07/03 – 07/10/03	2 and 3
21	07/15/03 – 07/18/03	2
22	08/01/03 – 08/04/03	2 and 3
23	08/12/03 – 08/15/03	2
24	08/22/03 – 08/25/03	2 and 3
25	09/03/03 – 09/06/03	2 and 3
26	09/16/03 – 09/19/03	2
27	10/05/03 – 10/08/03	2

**Table 3. Target Compound Detection Limits: Method Detection Limits (MDLs)
and Analytical Detection Limits (ADLs)**

VOC	MDL				ADL ($\mu\text{g}/\text{m}^3$)
	Mass ($\mu\text{g}/\text{mL}$)		Conc. ($\mu\text{g}/\text{m}^3$)		
	Lot 1	Lot 2	Lot 1	Lot 2	
n-Pentane	0.07	0.20	0.46	1.36	0.07
Methylene chloride	0.10	0.06	0.68	0.41	0.54
MTBE	0.08	0.01	0.61	0.08	0.08
n-Hexane	0.05	0.05	0.34	0.34	0.07
Methylcyclopentane	0.02	0.02	0.18	0.18	0.07
Methyl ethyl ketone	1.40	0.90	9.80	6.30	0.07
Chloroform	0.01	0.01	0.07	0.07	0.07
2,3-Dimethylpentane	0.02	0.18	0.16	1.44	0.08
Carbon tetrachloride	0.02	0.02	0.16	0.16	0.08
Benzene	0.18	0.07	1.24	0.48	0.07
Trichloroethylene	0.02	0.02	0.15	0.15	0.08
Toluene	0.22	0.35	1.65	2.63	0.08
Tetrachloroethylene	0.02	0.03	0.18	0.27	0.09
Ethyl benzene	0.03	0.03	0.26	0.26	0.09
n-Nonane	0.02	0.02	0.17	0.17	0.09
m&p-Xylenes	0.04	0.06	0.37	0.55	0.09
o-Xylene	0.02	0.02	0.20	0.20	0.10
Styrene	0.03	0.01	0.40	0.13	0.13
α -Pinene	0.02	0.06	0.20	0.61	0.10
n-Decane	0.07	0.04	0.67	0.38	0.10
1,3,5-Trimethylbenzene	0.01	0.01	0.09	0.09	0.09
1-Ethyl-2-methyl benzene	0.01	0.02	0.09	0.19	0.09
β -Pinene	0.02	0.02	0.20	0.20	0.10
1,2,4-Trimethylbenzene	0.02	0.02	0.19	0.19	0.10
d-Limonene	0.06	0.10	0.64	1.06	0.11
1,2,3-Trimethylbenzene	0.01	0.02	0.10	0.19	0.10
p-Dichlorobenzene	0.34	0.08	3.77	0.89	0.11
Naphthalene	0.02	0.02	0.18	0.18	0.09

Table 4. Precision of Analytical Duplicates: Percent Relative Difference (Absolute) Between Pairs

VOC	N	Mean	Median
n-Pentane	18	18.9	6.0
MTBE	18	6.3	3.4
n-Hexane	18	17.7	5.4
Methylcyclopentane	18	29.7	5.8
Chloroform	18	14.2	3.1
Carbon tetrachloride	18	7.5	6.9
Benzene	18	10.8	5.4
Trichloroethylene	18	17.5	13.8
Toluene	18	6.8	2.2
Tetrachloroethylene	18	28.1	15.8
Ethyl benzene	18	13.8	3.7
m&p-Xylenes	18	8.1	5.6
o-Xylene	18	8.9	7.4
α -Pinene	18	28.5	7.5
n-Decane	18	*	*
1,3,5-Trimethylbenzene	18	15.6	13.4
1-Ethyl-2-methyl benzene	18	14.2	9.4
1,2,4-Trimethylbenzene	18	7.2	5.6
d-Limonene	18	17.2	17.1
1,2,3-Trimethylbenzene	18	11.4	2.1
p-Dichlorobenzene	18	9.6	8.2

* Not calculated because more than half the samples were analytically nondetectable.

Table 5. Statistical Summary of 1.0 µg/mL Calibration Checks

VOC	N	Mean	Std. Deviation
1,3-Butadiene	18	4.85 ¹	0.62
n-Pentane	18	1.04	0.12
Isoprene	18	0.99	0.08
Methylene chloride	18	1.03	0.10
MTBE	18	0.97	0.25
n-Hexane	18	0.98	0.11
Chloroprene	18	1.04	0.12
Methylcyclopentane	18	0.94	0.06
Methyl ethyl ketone	18	1.04	0.11
Chloroform	18	1.10	0.10
2,3-Dimethylpentane	18	0.97	0.05
Carbon tetrachloride	18	1.11	0.16
Benzene	18	1.00	0.06
Trichloroethylene	18	1.02	0.06
Toluene	18	1.00	0.08
Tetrachloroethylene	18	0.99	0.06
Ethyl benzene	18	1.05	0.07
n-Nonane	18	1.02	0.10
m&p-Xylenes	18	2.16 ²	0.12
o-Xylene	18	1.05	0.06
Styrene	18	1.04	0.09
α-Pinene	18	1.02	0.09
n-Decane	18	1.02	0.14
1,3,5-Trimethylbenzene	18	1.07	0.06
1-Ethyl-2-methyl benzene	18	1.05	0.07
β-Pinene	18	1.05	0.13
1,2,4-Trimethylbenzene	18	1.05	0.08
d-Limonene	18	0.98	0.13
1,2,3-Trimethylbenzene	18	1.06	0.07
p-Dichlorobenzene	18	1.04	0.09
Naphthalene	18	1.04	0.11

¹ This standard mix contains 5 µg/mL of butadiene.

² This standard mix contains 1 µg/mL of each of the isomers (m-xylene and p-xylene)

Table 6. Precision of Duplicate Samples: Percent Relative Difference (Absolute) Between Pairs

VOC	N	Mean	Median
n-Pentane	115	22.4	8.1
MTBE	115	17.2	5.0
n-Hexane	115	21.9	6.0
Methylcyclopentane	115	22.1	8.7
Chloroform	115	33.3	12.8
Carbon tetrachloride	115	12.3	6.5
Benzene	115	14.8	7.5
Trichloroethylene	115	30.1	9.4
Toluene	115	22.5	12.2
Tetrachloroethylene	115	28.9	19.8
Ethyl benzene	115	16.8	7.7
m&p-Xylenes	115	16.2	6.6
o-Xylene	115	16.6	7.9
α -Pinene	115	26.2	13.2
n-Decane	115	30.6	9.1
1,3,5-Trimethylbenzene	115	20.3	9.9
1-Ethyl-2-methyl benzene	115	20.8	10.4
1,2,4-Trimethylbenzene	115	18.3	7.9
d-Limonene	115	45.9	22.2
1,2,3-Trimethylbenzene	115	32.0	10.8
p-Dichlorobenzene	115	41.6	22.9

Table 7. Summary Statistics for Phase II Samples by Sampling Site

VOC	Site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Pentane	Aldine MS	27	3.65	2.32	3.62	.03	8.49
	Aldine Centroid	25	3.98	2.20	3.45	.03	8.86
	Clinton MS	27	7.77	4.75	7.49	.03	20.38
	Clinton Centroid	26	5.33	3.42	4.32	.03	13.04
MTBE	Aldine MS	27	2.98	2.38	2.59	.04	10.54
	Aldine Centroid	25	3.55	2.57	2.90	.04	11.21
	Clinton MS	27	8.18	7.31	6.66	.31	31.02
	Clinton Centroid	26	3.57	2.57	3.32	.04	10.11
Hexane	Aldine MS	27	1.51	1.41	1.70	.03	4.85
	Aldine Centroid	25	1.56	1.39	1.40	.03	4.71
	Clinton MS	27	4.18	3.45	3.21	.03	11.39
	Clinton Centroid	26	1.94	1.72	1.56	.03	6.00
Methylcyclopentane	Aldine MS	27	.76	.60	.69	.04	2.54
	Aldine Centroid	25	.91	.55	.98	.04	2.62
	Clinton MS	27	1.95	1.72	1.72	.04	7.11
	Clinton Centroid	26	1.03	.68	1.04	.04	2.26
Chloroform	Aldine MS	27	.09	.08	.03	.03	.28
	Aldine Centroid	25	.06	.06	.03	.03	.25
	Clinton MS	27	.06	.05	.03	.03	.28
	Clinton Centroid	26	.06	.06	.03	.03	.25
Carbon tetrachloride	Aldine MS	27	.55	.12	.57	.04	.71
	Aldine Centroid	25	.53	.12	.54	.04	.66
	Clinton MS	27	.57	.11	.55	.36	.84
	Clinton Centroid	26	.54	.08	.55	.40	.71
Benzene	Aldine MS	27	1.37	.68	1.30	.03	2.86
	Aldine Centroid	25	1.55	.68	1.40	.36	2.93
	Clinton MS	27	2.14	1.00	1.97	.51	4.33
	Clinton Centroid	26	1.32	.51	1.45	.33	2.35
Trichloroethylene	Aldine MS	27	.09	.04	.09	.04	.19
	Aldine Centroid	25	.08	.04	.08	.04	.16
	Clinton MS	27	.08	.04	.08	.04	.15
	Clinton Centroid	26	.09	.04	.09	.04	.17
Toluene	Aldine MS	27	2.41	1.57	2.08	.04	6.76
	Aldine Centroid	25	2.41	1.52	1.93	.70	7.00
	Clinton MS	27	2.61	1.24	2.54	.96	6.10
	Clinton Centroid	26	1.75	.95	1.85	.23	3.79
Tetrachlorethylene	Aldine MS	27	.18	.10	.18	.05	.53
	Aldine Centroid	25	.18	.11	.18	.05	.48
	Clinton MS	27	.17	.10	.15	.05	.41
	Clinton Centroid	26	.16	.09	.13	.05	.40
Ethyl benzene	Aldine MS	27	.51	.28	.43	.04	1.37
	Aldine Centroid	25	.61	.30	.52	.30	1.54
	Clinton MS	27	.68	.27	.65	.32	1.24
	Clinton Centroid	26	.45	.20	.41	.20	1.08

Table 7. (Continued) Summary Statistics for Phase II Samples by Sampling Site

VOC	Site	N	Mean	Std. Deviation	Median	Minimum	Maximum
m/p-Xylene	Aldine MS	27	1.44	.85	1.21	.05	4.19
	Aldine Centroid	25	1.65	.88	1.39	.64	4.69
	Clinton MS	27	2.02	.95	2.02	.78	4.24
	Clinton Centroid	26	1.39	.67	1.25	.54	3.63
o-Xylene	Aldine MS	27	.54	.33	.45	.05	1.58
	Aldine Centroid	25	.62	.35	.52	.25	1.70
	Clinton MS	27	.69	.33	.69	.22	1.47
	Clinton Centroid	26	.46	.22	.43	.11	1.22
a-Pinene	Aldine MS	27	.60	.40	.50	.05	1.80
	Aldine Centroid	25	.64	.39	.66	.05	1.74
	Clinton MS	27	.28	.40	.19	.05	2.04
	Clinton Centroid	26	.75	.75	.59	.05	3.18
Decane	Aldine MS	27	.25	.22	.21	.05	.81
	Aldine Centroid	25	.37	.42	.28	.05	2.02
	Clinton MS	27	.33	.22	.34	.05	.81
	Clinton Centroid	26	.22	.17	.23	.05	.59
1,3,5-TMB	Aldine MS	27	.18	.11	.15	.04	.48
	Aldine Centroid	25	.20	.12	.16	.04	.57
	Clinton MS	27	.25	.19	.21	.04	1.08
	Clinton Centroid	26	.14	.06	.15	.04	.27
1-Ethyl-2-methyl benzene	Aldine MS	27	.17	.10	.14	.05	.45
	Aldine Centroid	25	.19	.11	.15	.05	.49
	Clinton MS	27	.22	.15	.19	.05	.86
	Clinton Centroid	26	.13	.07	.13	.05	.24
1,2,4-TMB	Aldine MS	27	.47	.34	.33	.05	1.51
	Aldine Centroid	25	.57	.37	.40	.21	1.71
	Clinton MS	27	.67	.60	.53	.12	3.39
	Clinton Centroid	26	.35	.18	.33	.05	.74
d-Limonene	Aldine MS	27	.19	.18	.05	.05	.73
	Aldine Centroid	25	.22	.20	.16	.05	.67
	Clinton MS	27	.16	.29	.05	.05	1.56
	Clinton Centroid	26	.36	.70	.05	.05	3.51
1,2,3-TMB	Aldine MS	27	.12	.09	.10	.05	.36
	Aldine Centroid	25	.15	.10	.12	.05	.40
	Clinton MS	27	.18	.16	.16	.05	.86
	Clinton Centroid	26	.09	.06	.05	.05	.23
p-Dichlorobenzene	Aldine MS	27	.27	.26	.16	.06	.83
	Aldine Centroid	25	.29	.27	.24	.06	1.05
	Clinton MS	27	.35	.41	.14	.06	1.31
	Clinton Centroid	26	.24	.27	.06	.06	1.01

Table 8. Summary of Results of Wilcoxon Signed-Ranks Tests: Differences Between Measurements at Monitoring Station vs. Centroid

VOC	Aldine		Clinton	
	N	p-value	N	p-value
n-Pentane	25	0.03 *	26	0.00 **
MTBE	25	0.00 *	26	0.00 **
n-Hexane	25	0.32	26	0.00 **
Methylcyclopentane	25	0.01 *	26	0.00 **
Chloroform	25	0.02 **	26	0.66
Carbon tetrachloride	25	0.18	26	0.08
Benzene	25	0.02 *	26	0.00 **
Trichloroethylene	25	0.36	26	0.30
Toluene	25	0.97	26	0.00 **
Tetrachloroethylene	25	0.56	26	0.64
Ethyl benzene	25	0.00 *	26	0.00 **
m&p-Xylenes	25	0.00 *	26	0.00 **
o-Xylene	25	0.00 *	26	0.00 **
α -Pinene	25	0.69	26	0.00 *
n-Decane	25	0.18	26	0.03 **
1,3,5-Trimethylbenzene	25	0.02 *	26	0.00 **
1-Ethyl-2-methyl benzene	25	0.01 *	26	0.00 **
1,2,4-Trimethylbenzene	25	0.00 *	26	0.00 **
d-Limonene	25	0.25	26	0.02 *
1,2,3-Trimethylbenzene	25	0.00 *	26	0.00 **
p-Dichlorobenzene	25	0.62	26	0.16

* Centroid measurements significantly greater than MS.

** Centroid measurements significantly less than MS.

Ambient Air Toxics in the Houston-Galveston Area with High and Low TRI Emissions – A Pilot Study of Temporal and Spatial Concentrations Using Passive Sampling Devices (PSDs)

Phase III Supplementary Monitoring

I. Introduction

This report summarizes the results of a monitoring project conducted as a supplement to Phase III of a multiple-phase research project intended to evaluate and demonstrate the utility of employing passive (diffusive) air samplers to investigate the temporal and spatial variability of ambient air concentrations of selected air toxics in the Houston-Galveston area. The results of Phase I (Morandi and Stock, 2001) indicated that the 3M 3500 Organic Vapor Monitor (OVM) could be successfully used to monitor short-term ambient air concentrations of a number of volatile organic compounds (VOCs). A sampling duration of 72 hours (3 days) was determined to be optimal. A limited comparison of OVM measurements with those from a continuous gas chromatograph (GC) at the same site indicated good agreement. A comparison of a modification of the OVM (diffusion path halved) with the original OVM indicated high correlation of measurements, but with an increased sampling rate somewhat less than that theoretically predicted.

During Phase II (Stock and Morandi, 2003), a series of 72-hour OVM samples were collected over the period of a year at two central air monitoring stations and, simultaneously, at the centroids of the census tracts in which each of the monitoring stations was located. Samples were collected approximately once every 12 days in two Houston areas, Aldine, with no Toxic Release Inventory (TRI) sources within 2 miles of the Aldine monitoring station, and Clinton Park, with 10 TRI sites within 2 miles of the Clinton Drive monitoring station. Statistically significant differences between concentrations measured at the monitoring station and at the centroid of the monitoring station's census tract were found for a number of target VOCs in both areas. In Clinton Park, the monitoring station overpredicted concentrations of thirteen compounds at the centroid site. In Aldine, the monitoring station underpredicted concentrations of eleven compounds at the centroid site. The observed intersite concentration differences were consistent with the presumptive differential impact of automotive emissions at each site.

The objective of Phase III (Stock and Morandi, 2003) was to perform a more intensive spatial monitoring in the areas surrounding three central monitoring stations (Aldine, Clinton Drive, and Deer Park). During each of six sampling events, OVMs were deployed outside ten residences in each area, within a 2-mile radius of the central site. The sampling frequency was approximately every 24 days, over a 4-month period (late May to early September, 2003). The results suggested

that passive air samplers can be used to measure differences in ambient concentrations of VOCs within a relatively small geographic area. Furthermore, it appeared that measurements of VOCs at central monitoring stations are not generally representative of locations within a 2-mile radius. Local sources of VOCs, presumably nearby automotive emissions and the use of consumer products, may produce elevated concentrations outside homes.

The purposes of this supplementary monitoring project for Phase III were two-fold: (1) to confirm whether the elevated concentrations of target VOCs observed during the previous warm-weather sampling would persist in cooler weather; and (2) to investigate the effect of sampler position on measured concentrations.

II. Target Compounds and Sampling Locations

The same 31 target VOCs as were employed in the Phases 2 and 3 monitoring (Stock and Morandi, 2003) were also utilized here. These compounds are presented in Table 1, in the order of elution from the GC column, along with the method detection limits (MDLs) determined for the current study.

Five of the houses in each of the Aldine and Clinton study areas that had participated in the original Phase III sampling were selected for re-sampling. These houses were chosen because of observed elevated concentrations of one or more VOCs measured outside the homes, relative to the central monitoring station. No homes in the Deer Park area were included in this study since outdoor concentrations appeared relatively homogeneous throughout this area. All homeowners of the 10 selected homes agreed to participate in the follow-up study. Table 2 lists the selected homes and the measurements responsible for their selection. As before, simultaneous monitoring was also performed on the roofs of the trailers at the TCEQ Aldine and Clinton Drive monitoring stations (MS). Locations and characteristics of the study areas and monitoring stations have been described previously (Stock and Morandi, 2003).

III. Methods

Sampling

OVM samples were collected over two 72-hour sampling periods, February 28 – March 2, 2004 and April 16 – 19, 2004. These sampling periods represented more moderate weather conditions than the previous summertime Phase III samplings. In order to investigate the possibility that specific placement positions of the OVMS outside some homes may have been unduly influenced by very localized sources of VOC emissions (e.g., idling cars, use of consumer products), multiple positions were used for OVM placement at all homes. At each of the two homes with the largest number of target compounds with clearly elevated levels in the previous monitoring (i.e., House A7 in Aldine and House C10 in Clinton), 5 OVMS were placed at different positions around the

house, including one placed at the position employed for the previous six Phase III sampling periods (“usual” position). See Figures 1 and 2 for these sample positions. Note that sample position 1 is the usual position. At each of the remaining 8 homes, two OVMS were placed at different positions on the front side of the house, one in the usual position and the other at a distance from this position. As before, all samplers were positioned to have some protection from direct rain and sun, e.g., under the house eaves.

In addition to the house samples, simultaneous measurements were conducted at each central monitoring station, using the roof sampling stand as described in the previous reports. During each sampling period at each monitoring station, two samples and one field blank were positioned as usual, under the protective cover of the stand. Two additional samples were attached to the outside of the stand so that they extended beyond the protective cover, thus being exposed to the elements. These “unprotected” OVMS were positioned in the horizontal plane, with the windscreen side facing down. This comparison was performed in order to begin evaluating the possible impact of exposure of OVMS to direct sun and rain. This is important, because some sampling locations may not afford protection from the elements, e.g., census tract centroids.

Analysis

At the end of each sampling period all OVMS were retrieved, capped, transported in hard plastic coolers with blue-ice packs, and stored under refrigeration until analysis, which was within one week of retrieval. Extraction and analytical procedures have been described in detail previously (Chung et al., 1999; Morandi and Stock, 2000). Analysis was performed using a HP 6890 Series GC with a 5973 MSD and EnviroQuant software. The column employed was a Restek (RTX-624, 60m 0.25mm ID with 1.4 um thickness column (Restek Corp., Bellefonte, PA; catalog # 10969). Samples were analyzed in 2 analytical batches. Each analysis consisted of 38 OVMS (34 samples, 2 field blanks and 2 lab blanks).

Quality Assurance

As indicated above, a field blank (FB) was deployed at each central monitoring station during each sampling period. A FB is an OVM whose outer plastic ring and windscreen have been removed and replaced with the analytical cap, making sure the ports on the cap and the cap itself are closed tightly. The FB is then positioned on the sampling stand near the field sample(s), and collected, handled, stored and analyzed with the corresponding samples. Two laboratory blanks (LB) were analyzed in each analytical batch. Lab blanks are OVMS removed from factory-sealed cans immediately prior to extraction and analysis. A total of 8 blanks (4 FB and 4 LB) were utilized for determining the mean blank correction for all sample masses, and the method detection limit (MDL).

During each analytical batch, two duplicate sample analyses were run (at the middle and end of

the batch), each followed by a 1 ug/mL standard (calibration check) and a solvent wash.

Calculations and Data Analysis

All calculations of air concentrations, analyses of data, statistical tests, and graphs were produced using SPSS for Windows, v. 11.5 (SPSS, Inc., Chicago, IL). Statistical significance was defined as $p < 0.05$.

IV. Results

All OVM sample concentrations of 1,3-butadiene, isoprene and chloroprene were analytically nondetectable. Most measurements (more than half) of methylene chloride, naphthalene, trichloroethylene and β -pinene were also nondetectable, with no apparent patterns. All but 5 measurements of methyl ethyl ketone were far below the MDL. Summary statistics for the remaining 23 target VOCs are presented in Table 3 (Aldine) and Table 4 (Clinton). For all statistical summaries and plots, all analytically nondetectable concentrations (≤ 0) were replaced by one-half the analytical detection limit (ADL). 72-hour concentration ADLs were provided in a previous report (Stock and Morandi, 2003), and are typically 0.1 ug/m^3 . Method detection limits (MDLs) were determined as described previously (Chung et al. 1999; Stock and Morandi, 2003) and are given in Table 1. Detectable measurements less than the MDL were included because, although the measurements are increasingly uncertain as values fall below the MDL, these estimates are considered better than any substitute value.

A more useful summary of the monitoring results by area is presented in Appendix E, where box plots are employed to graphically compare measurements, by sampling period, at the, houses and central monitoring station (MS) in each study area, for the 23 compounds. For the two houses with five OVMs (Aldine House 7 and Clinton House 10), outliers and extreme values are labeled with position number of the sample (see Figures 1 and 2). As noted for the previous Phase III sampling, the concentrations of most compounds are higher in the Clinton area than the Aldine area, as judged from a comparison of median concentrations at the central monitoring stations.

Comparisons across Sites and Dates

Aldine

In the Aldine area, measured concentrations at all sites appear higher during the second monitoring period than the first for the more volatile target compounds (pentane, MTBE, hexane and methylcyclopentane). A consistent difference between sampling dates is not observed for the remaining compounds. Maximum hourly temperatures were $8\text{-}15^\circ \text{ F}$ higher at the Aldine MS during the later monitoring period.

As was seen previously with the Phase III monitoring results, the Aldine central monitoring station measurements frequently underestimate concentrations outside of homes in the area. This is especially noticeable for Houses A1, A3 and A6 during the second sampling period. The general agreement between multiple samples at the homes (with the exception of House A7) indicates that there are no important positional effects, and that the measurements are representative of the general air mass near the homes. The pattern of elevated levels of multiple VOCs noted above is consistent with a relatively constant wind direction from the south and southeast during the second sampling period (wind direction was much more variable during the first period, with significant contributions from northerly winds). Houses A1 and A3 are both approximately 0.5 mi. northwest of a major freeway (route 59), and Houses A1 and A6 are 0.2-0.3 mi. north of a major area road (Aldine Mail Route). The Aldine MS is south of Aldine Mail Route and at least 1 mile northwest of the freeway.

As already noted, the obvious exception to the observation of good agreement among multiple samples at the homes is House A7. The box plots show that for most compounds, a single extremely elevated measurement is observed for position 1 at this house during the second sampling period. This result strongly suggests the influence of a strong source very near this sample position. The positional effect will be examined in more detail later.

Clinton

Patterns are a bit more complex in the Clinton area. Concentrations at all locations were consistently higher during the first sampling period than during the second for MTBE, toluene, ethyl benzene, the xylenes, the trimethylbenzenes, and ethylmethylbenzene. The opposite pattern was observed for hexane. The clearest pattern in these plots is the significantly elevated levels of many VOCs at Houses C10 and C11 for one or the other sampling period. With the exception of these two houses, the Clinton central monitoring station appeared fairly representative of concentrations measured outside homes during both sampling periods. Unlike House A7 in Aldine, the multiple samples collected at House C10 were in generally good agreement, with the exception of the sample at position 2 (see Figure 2) which was frequently an elevated outlier for the second sampling. This agreement suggests the influence of one or more sources affecting a wider area. The positional effect will be examined in more detail below.

The differences in concentrations of many target pollutants between the Clinton MS and Houses C10 and C11 implies that this central monitoring site is not representative of the air quality near these homes. Although both homes are located within 1 mi. of the Clinton Drive MS, they are located in the Manchester neighborhood, across the Houston Ship Channel from the MS, and approximately 1.1-1.7 mi. north of several major petrochemical facilities. There are several additional industrial facilities (e.g., Port of Houston) within 1 mi. of these homes, west, north and east of them. A major freeway (LaPorte Freeway) is 1 mi. to the south, and a major interstate

highway (Loop I-610) is within a 0.5 mi to the west, although it is significantly elevated in this area.

Effect of OVM Placement Position

The spatial variation of VOC concentrations around Houses A7 and C10 is depicted in bar graphs in Appendix F. The height of the bars represents the concentrations of individual samples at the indicated positions, as well as the mean concentrations of the four samples at the area MS. As indicated previously, the sample positions are shown in the schematic diagrams of each house (Figures 1 and 2), with position 1 designating the position employed for the previous Phase III samples. For each house, graphs are shown for 12 representative compounds.

The plots for House A7 confirm the lack of homogeneity of concentrations measured outside this home, especially during the second sampling period. These results are consistent with the elevated levels of many compounds observed at this house in the previous Phase III samples, since position 1 (usual position) was employed for all samples. This OVM placement position is under the house eaves, directly above the garage door. From an interview with the house residents conducted before the beginning of the supplemental sampling it was learned that the garage and driveway areas were strong potential sources of VOCs. The husband's tree-cutting business was conducted from the house, and he stored and serviced the gasoline-powered equipment in the garage (with door open) and driveway. In addition, many household-cleaning products were stored in the garage. Also, a vehicle was usually kept idling in the driveway for a period in the mornings, and it was usually washed and waxed every weekend in the driveway. While the second sampling period included an entire weekend, including Friday afternoon and Saturday morning, the first period was started mid-morning on a Saturday, in cooler weather.

In contrast to House A7, the plots for House C10 indicate a more spatially homogeneous elevation of concentrations of some target compounds during one or the other sampling periods. These data show that the elevated levels of compounds observed in the previous Phase III samples were not due to the usual placement position (position 1) above a parked car in a carport, but rather from a source affecting a wider area. The reason for the relatively higher concentrations of several compounds measured in position 2 samples is unknown. Although this was the only sample position on the west side of the house, it is unlikely that there would be a differential impact of a general ambient air source from that direction, especially considering that the winds were consistently from the south and southeast during the second sampling period, when this effect was most noticeable. Considering the compounds that were most elevated at this sample position, the impact of consumer products, perhaps originating indoors and escaping through the window near this position, is more likely. Elevated levels of compounds associated with automotive and industrial emissions showed two different patterns, perhaps suggesting different major sources. While concentrations of MTBE, m/p-xylene, o-xylene and ethyl benzene (last two not shown) were significantly elevated, relative to the MS, during the first sampling period, the opposite was true

for concentrations of pentane, hexane, methylcyclopentane (not shown), benzene and styrene, which were considerably higher than the MS levels during the second sampling period. The wind patterns at the Clinton Drive MS for both these periods were the same as for the Aldine MS, i.e., a relatively constant wind direction from the south and southeast during the second sampling period with a much more variable wind direction occurring during the first period, which included significant contributions from northerly winds. Therefore, a differential influence of major sources, both automotive and industrial, might be expected for the two sampling periods.

V. Conclusions

The results of this supplementary sampling project serve to complement and further elucidate the results of the Phase III study. Furthermore, they clearly reinforce the unique advantages of passive samplers in determining the temporal and spatial variation of concentrations of important urban air toxics.

1. Concentrations of many VOCs in two Houston neighborhoods are frequently underestimated by measurements at central monitoring stations.
2. Elevated levels of compounds appear to be persistent, i.e., similar results were observed during summertime sampling in Phase III and the cooler weather sampling reported here.
3. Spatial mapping of concentrations around homes can be successfully used to differentiate between observed elevated concentrations caused by specific localized resident activities (House A7) and those due to more remote sources affecting a larger area (House C10).

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Table 1. Target Compounds and 72-Hour Method Detection Limits.

VOC	MDL ($\mu\text{g}/\text{m}^3$)
1,3-Butadiene	2.29
n-Pentane	1.33
Isoprene	.91
Methylene chloride	.55
MTBE	.45
n-Hexane	.70
Chloroprene	.13
Methylcyclopentane	.17
Methyl ethyl ketone	1.34
Chloroform	.03
2,3-Dimethylpentane	.41
Carbon tetrachloride	.12
Benzene	.24
Trichloroethylene	.23
Toluene	3.07
Tetrachloroethylene	.09
Ethyl benzene	.05
n-Nonane	.19
m&p-Xylenes	.14
o-Xylene	.08
Styrene	.25
α -Pinene	.37
n-Decane	.58
1,3,5-Trimethylbenzene	.13
1-Ethyl-2-methyl benzene	.15
β -Pinene	.19
1,2,4-Trimethylbenzene	.03
d-Limonene	.40
1,2,3-Trimethylbenzene	.04
p-Dichlorobenzene	.67
Naphthalene	.15

Table 2. Phase III Homes Selected for This Study.

Aldine Area Houses	Distance/Direction from MS	Reason Selected
A1	0.54 mi./NE	Relatively high median for many compounds
A3	0.78 mi./NE	Relatively high median for many compounds; high chloroform
A4	0.62 mi./NW	Highest median for p-dichlorobenzene; 2 nd highest for several others
A6	0.98 mi./NW	Highest median for tetrachloroethylene
A7	0.75 mi./SW	Elevated concentrations of 20 compounds
Clinton Area Houses		
C2	0.25 mi./NW	Elevated concentrations of methylene chloride and d-limonene
C5	1.89 mi./NW	Elevated concentrations of naphthalene
C6	1.86 mi./NW	Elevated concentrations of p-dichloro-benzene; highest median for TMB
C10	0.82 mi./SW	Highest concentrations of 11 compounds
C11	0.98 mi./SW	Relatively high median for many compounds

Table 3. Summary Statistics for Supplemental Phase III Samples in Aldine Area (ug/m3).

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum		
Pentane	28-FEB-2004	1	2	1.69	.30	1.69	1.48	1.90		
		3	2	.80	1.08	.80	.04	1.57		
		4	2	.82	1.11	.82	.04	1.60		
		6	2	.04	.00	.04	.04	.04		
		7	5	1.09	1.00	.64	.04	2.38		
	16-APR-2004	MS	4	.33	.35	.29	.04	.71		
		1	2	6.21	.14	6.21	6.11	6.31		
		3	2	5.82	1.29	5.82	4.91	6.74		
		4	2	3.77	.48	3.77	3.43	4.11		
		6	2	3.45	.25	3.45	3.28	3.63		
		7	5	4.71	3.66	3.07	2.88	11.25		
		MS	4	3.79	.20	3.77	3.60	4.02		
		MTBE	28-FEB-2004	1	2	5.19	.54	5.19	4.82	5.57
				3	2	6.04	.63	6.04	5.60	6.48
4	2			2.70	.38	2.70	2.43	2.96		
6	2			2.51	.36	2.51	2.26	2.76		
7	5			4.11	2.19	3.02	2.68	7.83		
16-APR-2004	MS		4	1.78	.06	1.80	1.70	1.83		
	1		2	10.47	1.12	10.47	9.67	11.26		
	3		2	8.38	2.71	8.38	6.47	10.30		
	4		2	3.76	.29	3.76	3.55	3.96		
	6		2	8.40	2.05	8.40	6.94	9.85		
	7		5	7.89	10.35	3.14	2.42	26.33		
	MS		4	2.97	.13	2.97	2.81	3.14		
	Hexane		28-FEB-2004	1	2	.37	.18	.37	.24	.50
				3	2	.32	.40	.32	.04	.60
4		2		.65	.33	.65	.42	.88		
6		2		.65	.13	.65	.56	.74		
7		5		.73	.29	.61	.49	1.18		
16-APR-2004		MS	4	.35	.04	.36	.29	.40		
		1	2	2.96	.18	2.96	2.83	3.09		
		3	2	2.55	.64	2.55	2.10	3.00		
		4	2	1.54	.08	1.54	1.49	1.60		
		6	2	1.60	.34	1.60	1.36	1.84		
		7	5	1.88	2.44	.81	.72	6.24		
		MS	4	1.07	.39	.90	.83	1.66		
		Methylcyclopentane	28-FEB-2004	1	2	.82	.12	.82	.73	.90
				3	2	.74	.11	.74	.66	.81
4	2			.65	.01	.65	.65	.65		
6	2			.57	.10	.57	.50	.64		
7	5			.80	.34	.70	.53	1.35		
16-APR-2004	MS		4	.57	.13	.57	.41	.73		
	1		2	1.65	.31	1.65	1.43	1.87		
	3		2	1.30	.23	1.30	1.14	1.47		
	4		2	.93	.04	.93	.90	.96		
	6		2	1.69	.34	1.69	1.44	1.93		
	7		5	1.54	1.61	.83	.66	4.41		
	MS		4	.79	.05	.78	.74	.85		

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Chloroform	28-FEB-2004	1	2	.10	.02	.10	.08	.12
		3	2	.07	.00	.07	.07	.07
		4	2	.09	.04	.09	.06	.12
		6	2	.07	.02	.07	.05	.08
		7	5	.06	.02	.06	.04	.09
		MS	4	.09	.03	.08	.07	.14
	16-APR-2004	1	2	.10	.05	.10	.07	.14
		3	2	.06	.02	.06	.05	.08
		4	2	.06	.00	.06	.06	.06
		6	2	.06	.01	.06	.05	.06
		7	5	.08	.03	.07	.06	.13
		MS	4	.08	.02	.08	.06	.10
		Dimethylpentane	28-FEB-2004	1	2	.04	.00	.04
3	2			.04	.00	.04	.04	.04
4	2			.04	.00	.04	.04	.04
6	2			.04	.00	.04	.04	.04
7	5			.04	.00	.04	.04	.04
MS	4			.04	.00	.04	.04	.04
16-APR-2004	1		2	.66	.15	.66	.55	.76
	3		2	.61	.37	.61	.35	.87
	4		2	.04	.00	.04	.04	.04
	6		2	.55	.07	.55	.49	.60
	7		5	.39	.68	.04	.04	1.61
	MS		4	.09	.09	.04	.04	.23
	Carbon tetrachloride		28-FEB-2004	1	2	.53	.05	.53
3		2		.49	.00	.49	.49	.49
4		2		.52	.06	.52	.47	.56
6		2		.47	.03	.47	.45	.49
7		5		.49	.04	.51	.43	.52
MS		4		.54	.02	.54	.52	.57
16-APR-2004		1	2	.46	.05	.46	.43	.50
		3	2	.44	.02	.44	.42	.45
		4	2	.53	.01	.53	.53	.53
		6	2	.46	.00	.46	.46	.46
		7	5	.51	.07	.48	.46	.62
		MS	4	.54	.03	.53	.52	.59
		Benzene	28-FEB-2004	1	2	1.24	.13	1.24
3	2			1.03	.03	1.03	1.01	1.05
4	2			.90	.03	.90	.88	.92
6	2			.76	.10	.76	.69	.83
7	5			1.00	.26	.91	.72	1.35
MS	4			.88	.02	.89	.86	.89
16-APR-2004	1		2	1.33	.25	1.33	1.16	1.50
	3		2	1.10	.07	1.10	1.05	1.15
	4		2	.87	.16	.87	.76	.98
	6		2	1.06	.01	1.06	1.05	1.07
	7		5	1.13	1.07	.64	.52	3.03
	MS		4	.71	.08	.73	.60	.78

Table 3. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Toluene	28-FEB-2004	1	2	5.02	.22	5.02	4.86	5.18
		3	2	3.52	1.46	3.52	2.49	4.55
		4	2	2.44	2.53	2.44	.65	4.23
		6	2	4.25	.06	4.25	4.21	4.29
		7	5	4.74	1.30	4.58	3.08	6.08
	16-APR-2004	MS	4	3.21	.56	3.08	2.75	3.95
		1	2	4.34	1.39	4.34	3.35	5.33
		3	2	2.34	.44	2.34	2.03	2.66
		4	2	1.85	.42	1.85	1.55	2.15
		6	2	2.41	.17	2.41	2.28	2.53
		7	5	3.87	5.26	1.68	1.14	13.27
		MS	4	1.40	.25	1.31	1.21	1.75
		Tetrachloroethylene	28-FEB-2004	1	2	.06	.01	.06
3	2			.10	.04	.10	.07	.13
4	2			.13	.01	.13	.13	.14
6	2			.17	.04	.17	.15	.20
7	5			.17	.02	.17	.16	.19
16-APR-2004	MS		4	.11	.03	.11	.08	.14
	1		2	.08	.01	.08	.08	.09
	3		2	.07	.05	.07	.04	.10
	4		2	.09	.05	.09	.06	.13
	6		2	.14	.04	.14	.11	.17
	7		5	.09	.05	.07	.05	.17
	MS		4	.11	.03	.11	.06	.14
	Ethyl benzene		28-FEB-2004	1	2	.87	.21	.87
3		2		.44	.08	.44	.38	.50
4		2		.38	.01	.38	.38	.39
6		2		.36	.05	.36	.33	.39
7		5		.49	.23	.37	.33	.88
16-APR-2004		MS	4	.29	.01	.29	.28	.31
		1	2	.81	.14	.81	.71	.90
		3	2	.57	.07	.57	.52	.63
		4	2	.36	.06	.36	.31	.40
		6	2	.48	.00	.48	.48	.48
		7	5	.84	1.20	.33	.21	2.98
		MS	4	.26	.02	.26	.24	.30
		Nonane	28-FEB-2004	1	2	.23	.26	.23
3	2			.05	.00	.05	.05	.05
4	2			.17	.18	.17	.05	.30
6	2			.20	.22	.20	.05	.36
7	5			.11	.15	.05	.05	.38
16-APR-2004	MS		4	.05	.00	.05	.05	.05
	1		2	.53	.07	.53	.48	.58
	3		2	.29	.06	.29	.25	.34
	4		2	.19	.21	.19	.05	.34
	6		2	.17	.17	.17	.05	.29
	7		5	.25	.32	.05	.05	.79
	MS		4	.14	.11	.12	.05	.27

Table 3. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
m/p-Xylene	28-FEB-2004	1	2	2.64	.71	2.64	2.14	3.14
		3	2	1.10	.15	1.10	.99	1.21
		4	2	.95	.10	.95	.88	1.02
		6	2	1.05	.19	1.05	.92	1.19
		7	5	1.52	.93	1.06	.87	3.13
		MS	4	.76	.04	.76	.71	.81
	16-APR-2004	1	2	2.81	.43	2.81	2.50	3.12
		3	2	1.72	.17	1.72	1.60	1.84
		4	2	1.13	.21	1.13	.98	1.27
		6	2	1.82	.09	1.82	1.76	1.89
		7	5	2.85	3.86	1.22	.86	9.74
		MS	4	.91	.05	.91	.87	.97
		o-Xylene	28-FEB-2004	1	2	.81	.19	.81
3	2			.41	.06	.41	.37	.45
4	2			.34	.09	.34	.27	.40
6	2			.42	.02	.42	.40	.43
7	5			.52	.27	.40	.27	.97
MS	4			.30	.02	.31	.26	.32
16-APR-2004	1		2	.97	.17	.97	.85	1.08
	3		2	.71	.12	.71	.63	.80
	4		2	.40	.05	.40	.37	.44
	6		2	.62	.06	.62	.58	.66
	7		5	.97	1.31	.44	.28	3.31
	MS		4	.31	.02	.30	.29	.33
	Styrene		28-FEB-2004	1	2	.15	.13	.15
3		2		.06	.00	.06	.06	.06
4		2		.06	.00	.06	.06	.06
6		2		.06	.00	.06	.06	.06
7		5		.06	.00	.06	.06	.06
MS		4		.06	.00	.06	.06	.06
16-APR-2004		1	2	.13	.11	.13	.05	.20
		3	2	.13	.10	.13	.06	.21
		4	2	.15	.12	.15	.06	.23
		6	2	.12	.03	.12	.10	.14
		7	5	.17	.11	.15	.06	.34
		MS	4	.17	.06	.16	.12	.25
		a-Pinene	28-FEB-2004	1	2	.71	.06	.71
3	2			.50	.04	.50	.47	.53
4	2			.32	.07	.32	.27	.37
6	2			.51	.14	.51	.42	.61
7	5			.62	.53	.43	.28	1.57
MS	4			.28	.02	.27	.26	.31
16-APR-2004	1		2	.93	.15	.93	.82	1.04
	3		2	.36	.05	.36	.33	.39
	4		2	.35	.20	.35	.21	.49
	6		2	.17	.04	.17	.14	.20
	7		5	.33	.20	.22	.17	.65
	MS		4	.29	.03	.29	.26	.32

Table 3. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Decane	28-FEB-2004	1	2	.20	.11	.20	.13	.28
		3	2	.23	.14	.23	.14	.33
		4	2	.41	.08	.41	.35	.47
		6	2	.40	.16	.40	.29	.52
		7	5	.24	.11	.25	.09	.38
	16-APR-2004	MS	4	.16	.04	.14	.13	.22
		1	2	.81	.21	.81	.66	.96
		3	2	.22	.08	.22	.16	.27
		4	2	.28	.04	.28	.25	.31
		6	2	.15	.14	.15	.05	.25
		7	5	.37	.32	.26	.05	.90
		MS	4	.18	.04	.19	.13	.21
		1,3,5-TMB	28-FEB-2004	1	2	.27	.04	.27
3	2			.24	.08	.24	.19	.30
4	2			.18	.03	.18	.16	.20
6	2			.21	.02	.21	.20	.22
7	5			.22	.09	.18	.15	.36
16-APR-2004	MS		4	.13	.02	.14	.10	.15
	1		2	.34	.05	.34	.30	.37
	3		2	.33	.04	.33	.30	.35
	4		2	.18	.02	.18	.17	.19
	6		2	.27	.04	.27	.25	.30
	7		5	.39	.48	.19	.14	1.25
	MS		4	.13	.01	.13	.13	.14
	1-Ethyl-2-methyl benzene		28-FEB-2004	1	2	.21	.03	.21
3		2		.18	.03	.18	.16	.20
4		2		.14	.02	.14	.13	.15
6		2		.18	.04	.18	.16	.21
7		5		.20	.10	.15	.14	.37
16-APR-2004		MS	4	.13	.01	.13	.12	.15
		1	2	.27	.07	.27	.23	.32
		3	2	.23	.02	.23	.22	.25
		4	2	.15	.00	.15	.15	.15
		6	2	.19	.03	.19	.17	.21
		7	5	.29	.34	.15	.11	.89
		MS	4	.11	.01	.12	.10	.12
		1,2,4-TMB	28-FEB-2004	1	2	.61	.22	.61
3	2			.57	.19	.57	.44	.70
4	2			.26	.05	.26	.22	.29
6	2			.42	.04	.42	.39	.45
7	5			.51	.37	.31	.24	1.14
16-APR-2004	MS		4	.25	.02	.25	.23	.28
	1		2	.84	.21	.84	.69	.99
	3		2	.68	.09	.68	.62	.75
	4		2	.32	.06	.32	.28	.37
	6		2	.62	.08	.62	.56	.68
	7		5	1.03	1.51	.38	.21	3.73
	MS		4	.22	.02	.21	.19	.25

Table 3. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
d-Limonene	28-FEB-2004	1	2	.23	.01	.23	.23	.24
		3	2	.04	.01	.04	.03	.04
		4	2	.10	.06	.10	.06	.14
		6	2	.33	.11	.33	.26	.41
		7	5	.09	.10	.06	.01	.27
		MS	4	.05	.04	.06	.01	.09
	16-APR-2004	1	2	.21	.01	.21	.20	.21
		3	2	.12	.16	.12	.00	.23
		4	2	.28	.32	.28	.06	.51
		6	2	.08	.04	.08	.05	.11
		7	5	.43	.44	.16	.06	1.11
		MS	4	.10	.04	.09	.07	.15
1,2,3-TMB	28-FEB-2004	1	2	.20	.04	.20	.17	.23
		3	2	.13	.11	.13	.05	.21
		4	2	.11	.09	.11	.05	.17
		6	2	.12	.10	.12	.05	.19
		7	5	.10	.06	.05	.05	.17
		MS	4	.09	.06	.07	.05	.18
	16-APR-2004	1	2	.23	.06	.23	.19	.27
		3	2	.19	.03	.19	.17	.21
		4	2	.08	.05	.08	.05	.11
		6	2	.17	.03	.17	.15	.19
		7	5	.28	.31	.14	.11	.82
		MS	4	.09	.05	.08	.05	.16
p-Dichlorobenzene	28-FEB-2004	1	2	.30	.28	.30	.10	.50
		3	2	.25	.27	.25	.06	.44
		4	2	.57	.42	.57	.28	.87
		6	2	.61	.54	.61	.23	.99
		7	5	.17	.12	.11	.05	.33
		MS	4	.17	.13	.16	.06	.30
	16-APR-2004	1	2	.73	.26	.73	.55	.92
		3	2	.15	.01	.15	.14	.16
		4	2	.23	.07	.23	.18	.28
		6	2	.04	.02	.04	.03	.05
		7	5	.43	.41	.24	.01	1.03
		MS	4	.15	.20	.08	.00	.44

Table 4. Summary Statistics for Supplemental Phase III Samples in Clinton Area (ug/m3).

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum		
Pentane	28-FEB-2004	2	2	3.57	.66	3.57	3.10	4.03		
		5	2	2.75	.28	2.75	2.56	2.95		
		6	2	2.35	.28	2.35	2.15	2.55		
		10	5	5.93	1.22	5.30	4.78	7.70		
		11	2	6.99	1.61	6.99	5.85	8.13		
		MS	4	4.72	.37	4.67	4.39	5.14		
	16-APR-2004	2	2	3.02	.07	3.02	2.97	3.07		
		5	2	2.26	.41	2.26	1.97	2.55		
		6	2	2.44	.08	2.44	2.39	2.50		
		10	5	18.25	6.89	15.42	14.08	30.46		
		11	2	5.10	1.50	5.10	4.04	6.16		
		MS	4	3.23	.14	3.23	3.09	3.35		
		MTBE	28-FEB-2004	2	2	4.13	.69	4.13	3.64	4.62
				5	2	4.07	.49	4.07	3.72	4.42
6	2			4.32	.48	4.32	3.98	4.65		
10	5			8.05	.90	7.78	7.06	9.09		
11	2			10.05	3.41	10.05	7.63	12.46		
MS	4			3.28	.13	3.23	3.19	3.47		
16-APR-2004	2		2	1.42	.01	1.42	1.42	1.43		
	5		2	1.41	.20	1.41	1.27	1.55		
	6		2	1.34	.01	1.34	1.34	1.35		
	10		5	1.96	.17	2.02	1.68	2.13		
	11		2	4.31	1.49	4.31	3.26	5.36		
	MS		4	1.25	.01	1.25	1.24	1.28		
	Hexane		28-FEB-2004	2	2	1.07	.01	1.07	1.06	1.08
				5	2	.59	.07	.59	.54	.63
6		2		.84	.14	.84	.73	.94		
10		5		2.07	.23	2.06	1.76	2.41		
11		2		2.02	.00	2.02	2.02	2.02		
MS		4		1.53	.45	1.43	1.13	2.14		
16-APR-2004		2	2	1.67	.25	1.67	1.49	1.85		
		5	2	1.25	.41	1.25	.96	1.54		
		6	2	1.63	.13	1.63	1.53	1.72		
		10	5	18.77	3.22	18.06	16.09	24.08		
		11	2	5.71	1.52	5.71	4.63	6.79		
		MS	4	2.27	.19	2.27	2.05	2.48		
		Methylcyclopentane	28-FEB-2004	2	2	1.12	.37	1.12	.86	1.39
				5	2	.80	.07	.80	.75	.84
6	2			.84	.07	.84	.79	.89		
10	5			1.93	.30	1.91	1.55	2.36		
11	2			2.10	.47	2.10	1.77	2.43		
MS	4			1.40	.14	1.43	1.23	1.53		
16-APR-2004	2		2	1.16	.11	1.16	1.08	1.24		
	5		2	.84	.17	.84	.72	.96		
	6		2	1.13	.12	1.13	1.04	1.21		
	10		5	10.53	2.11	9.63	8.97	14.09		
	11		2	3.35	1.01	3.35	2.63	4.06		
	MS		4	1.30	.04	1.28	1.27	1.36		

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Chloroform	28-FEB-2004	2	2	.10	.03	.10	.08	.12
		5	2	.08	.03	.08	.06	.11
		6	2	.09	.03	.09	.06	.11
		10	5	.10	.03	.09	.07	.15
		11	2	.08	.03	.08	.06	.10
		MS	4	.10	.03	.09	.07	.13
	16-APR-2004	2	2	.10	.01	.10	.09	.10
		5	2	.06	.05	.06	.02	.09
		6	2	.07	.01	.07	.06	.07
		10	5	.11	.09	.08	.05	.26
		11	2	.06	.04	.06	.04	.09
		MS	4	.10	.01	.09	.09	.11
		Dimethylpentane	28-FEB-2004	2	2	.04	.00	.04
5	2			.04	.00	.04	.04	.04
6	2			.04	.00	.04	.04	.04
10	5			.48	.25	.58	.04	.65
11	2			.63	.16	.63	.52	.74
MS	4			.58	.69	.34	.04	1.60
16-APR-2004	2		2	.13	.13	.13	.04	.22
	5		2	.04	.00	.04	.04	.04
	6		2	.04	.00	.04	.04	.04
	10		5	2.13	.39	2.07	1.68	2.77
	11		2	.59	.27	.59	.40	.78
	MS		4	.04	.00	.04	.04	.04
	Carbon tetrachloride		28-FEB-2004	2	2	.53	.07	.53
5		2		.47	.05	.47	.43	.50
6		2		.51	.04	.51	.48	.54
10		5		.49	.01	.49	.47	.50
11		2		.52	.03	.52	.50	.54
MS		4		.57	.07	.58	.49	.63
16-APR-2004		2	2	.52	.01	.52	.51	.53
		5	2	.54	.03	.54	.52	.57
		6	2	.51	.01	.51	.50	.52
		10	5	.52	.05	.51	.46	.59
		11	2	.45	.12	.45	.37	.54
		MS	4	.57	.05	.54	.53	.65
		Benzene	28-FEB-2004	2	2	1.46	.71	1.46
5	2			.99	.28	.99	.79	1.19
6	2			1.16	.01	1.16	1.15	1.16
10	5			1.80	.12	1.78	1.67	1.93
11	2			1.69	.16	1.69	1.57	1.81
MS	4			1.58	.07	1.60	1.49	1.64
16-APR-2004	2		2	1.05	.20	1.05	.91	1.19
	5		2	.81	.16	.81	.70	.92
	6		2	.87	.09	.87	.81	.94
	10		5	5.93	1.46	5.41	4.93	8.44
	11		2	4.87	1.50	4.87	3.81	5.93
	MS		4	.99	.06	1.01	.90	1.03

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Toluene	28-FEB-2004	2	2	1.86	.33	1.86	1.63	2.09
		5	2	1.09	.02	1.09	1.08	1.10
		6	2	1.38	.36	1.38	1.13	1.64
		10	5	2.76	.32	2.71	2.40	3.12
		11	2	3.04	.21	3.04	2.89	3.19
	16-APR-2004	MS	4	2.17	.56	2.06	1.60	2.95
		2	2	1.49	.04	1.49	1.46	1.52
		5	2	.80	.27	.80	.61	.99
		6	2	.67	.07	.67	.62	.72
		10	5	2.57	1.40	2.05	1.71	5.05
		11	2	1.36	.48	1.36	1.02	1.70
		MS	4	1.68	.17	1.65	1.53	1.89
		Tetrachloroethylene	28-FEB-2004	2	2	.09	.05	.09
5	2			.16	.03	.16	.14	.18
6	2			.14	.04	.14	.11	.18
10	5			.25	.06	.25	.16	.32
11	2			.16	.04	.16	.14	.19
16-APR-2004	MS		4	.20	.04	.18	.16	.25
	2		2	.17	.01	.17	.16	.17
	5		2	.09	.03	.09	.07	.11
	6		2	.07	.01	.07	.06	.08
	10		5	.08	.02	.09	.05	.09
	11		2	.27	.09	.27	.21	.34
	MS		4	.19	.02	.18	.18	.22
	Ethyl benzene		28-FEB-2004	2	2	.49	.18	.49
5		2		.36	.07	.36	.31	.40
6		2		.38	.06	.38	.34	.42
10		5		.88	.03	.87	.84	.93
11		2		.83	.05	.83	.80	.86
16-APR-2004		MS	4	.63	.07	.62	.56	.71
		2	2	.35	.03	.35	.33	.37
		5	2	.24	.05	.24	.21	.28
		6	2	.19	.04	.19	.16	.21
		10	5	.25	.08	.22	.20	.39
		11	2	.27	.10	.27	.20	.33
		MS	4	.36	.02	.36	.34	.38
		Nonane	28-FEB-2004	2	2	.05	.00	.05
5	2			.05	.00	.05	.05	.05
6	2			.05	.00	.05	.05	.05
10	5			.52	.03	.51	.49	.57
11	2			.53	.01	.53	.52	.54
16-APR-2004	MS		4	.35	.21	.45	.05	.47
	2		2	.55	.07	.55	.51	.60
	5		2	.15	.15	.15	.05	.25
	6		2	.16	.16	.16	.05	.27
	10		5	.56	.18	.52	.44	.88
	11		2	.12	.10	.12	.05	.19
	MS		4	.66	.04	.67	.61	.69

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
m/p-Xylene	28-FEB-2004	2	2	1.40	.53	1.40	1.02	1.77
		5	2	.92	.10	.92	.85	.99
		6	2	1.00	.16	1.00	.89	1.11
		10	5	3.24	.14	3.27	3.04	3.42
		11	2	2.88	.20	2.88	2.74	3.03
	16-APR-2004	MS	4	1.90	.06	1.91	1.84	1.95
		2	2	1.22	.10	1.22	1.14	1.29
		5	2	.88	.22	.88	.73	1.04
		6	2	.65	.04	.65	.62	.68
		10	5	.82	.40	.67	.59	1.52
		11	2	.82	.24	.82	.64	.99
		MS	4	1.32	.06	1.32	1.25	1.38
		o-Xylene	28-FEB-2004	2	2	.45	.24	.45
5	2			.35	.02	.35	.33	.36
6	2			.40	.05	.40	.36	.43
10	5			.86	.05	.85	.81	.93
11	2			.82	.07	.82	.77	.87
16-APR-2004	MS		4	.61	.02	.61	.59	.63
	2		2	.40	.05	.40	.37	.44
	5		2	.28	.07	.28	.23	.33
	6		2	.22	.04	.22	.19	.25
	10		5	.26	.09	.22	.19	.41
	11		2	.27	.08	.27	.22	.33
	MS		4	.46	.03	.45	.43	.50
	Styrene		28-FEB-2004	2	2	.19	.18	.19
5		2		.08	.02	.08	.06	.09
6		2		.06	.00	.06	.06	.06
10		5		.47	.02	.47	.44	.50
11		2		.29	.01	.29	.28	.30
16-APR-2004		MS	4	.27	.02	.27	.25	.30
		2	2	.17	.02	.17	.16	.18
		5	2	.21	.07	.21	.16	.26
		6	2	.23	.03	.23	.20	.25
		10	5	.98	.09	1.02	.82	1.05
		11	2	1.81	.46	1.81	1.49	2.14
		MS	4	.20	.02	.20	.18	.22
		a-Pinene	28-FEB-2004	2	2	.11	.09	.11
5	2			.18	.04	.18	.15	.22
6	2			.12	.08	.12	.07	.18
10	5			.09	.05	.06	.05	.17
11	2			.13	.11	.13	.05	.20
16-APR-2004	MS		4	.14	.11	.11	.05	.29
	2		2	.18	.02	.18	.17	.20
	5		2	.23	.05	.23	.20	.27
	6		2	.23	.04	.23	.21	.26
	10		5	.14	.09	.20	.05	.21
	11		2	.05	.00	.05	.05	.05
	MS		4	.10	.08	.07	.05	.21

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
Decane	28-FEB-2004	2	2	.14	.03	.14	.12	.16
		5	2	.10	.03	.10	.08	.12
		6	2	.21	.00	.21	.20	.21
		10	5	.31	.06	.33	.24	.37
		11	2	.42	.03	.42	.40	.44
		MS	4	.55	.19	.53	.35	.79
	16-APR-2004	2	2	.47	.01	.47	.46	.48
		5	2	.17	.11	.17	.09	.24
		6	2	.16	.03	.16	.14	.18
		10	5	.47	.10	.50	.33	.58
		11	2	.16	.08	.16	.10	.21
		MS	4	.47	.08	.44	.41	.60
		MS	4	.47	.08	.44	.41	.60
1,3,5-TMB	28-FEB-2004	2	2	.20	.06	.20	.16	.24
		5	2	.15	.01	.15	.14	.16
		6	2	.16	.01	.16	.15	.16
		10	5	.23	.01	.23	.22	.24
		11	2	.30	.02	.30	.29	.31
		MS	4	.19	.10	.22	.05	.27
	16-APR-2004	2	2	.19	.00	.19	.19	.19
		5	2	.11	.02	.11	.09	.12
		6	2	.10	.01	.10	.10	.11
		10	5	.15	.02	.14	.13	.18
		11	2	.15	.03	.15	.12	.17
		MS	4	.20	.02	.21	.16	.21
		MS	4	.20	.02	.21	.16	.21
1-Ethyl-2-methyl benzene	28-FEB-2004	2	2	.16	.05	.16	.12	.19
		5	2	.12	.02	.12	.11	.14
		6	2	.13	.02	.13	.11	.14
		10	5	.19	.03	.18	.17	.23
		11	2	.22	.01	.22	.22	.23
		MS	4	.24	.03	.23	.20	.28
	16-APR-2004	2	2	.15	.01	.15	.14	.15
		5	2	.09	.07	.09	.05	.14
		6	2	.10	.01	.10	.09	.11
		10	5	.12	.02	.12	.10	.15
		11	2	.13	.05	.13	.10	.16
		MS	4	.18	.01	.18	.16	.19
		MS	4	.18	.01	.18	.16	.19
1,2,4-TMB	28-FEB-2004	2	2	.41	.23	.41	.25	.58
		5	2	.28	.06	.28	.24	.32
		6	2	.24	.04	.24	.22	.27
		10	5	.48	.04	.48	.43	.52
		11	2	.69	.03	.69	.67	.72
		MS	4	.59	.05	.58	.55	.65
	16-APR-2004	2	2	.38	.02	.38	.36	.40
		5	2	.20	.08	.20	.14	.26
		6	2	.14	.02	.14	.13	.16
		10	5	.23	.04	.24	.18	.27
		11	2	.28	.11	.28	.20	.36
		MS	4	.45	.04	.43	.42	.51
		MS	4	.45	.04	.43	.42	.51

Table 4. (Continued)

VOC	Start Date	id of home or monitoring site	N	Mean	Std. Deviation	Median	Minimum	Maximum
d-Limonene	28-FEB-2004	2	2	.07	.02	.07	.06	.08
		5	2	.06	.00	.06	.06	.06
		6	2	.06	.00	.06	.06	.06
		10	5	.07	.06	.06	.02	.18
		11	2	.12	.09	.12	.06	.19
		MS	4	.09	.09	.06	.02	.23
	16-APR-2004	2	2	.28	.05	.28	.24	.31
		5	2	.13	.10	.13	.06	.20
		6	2	.06	.03	.06	.04	.08
		10	5	.29	.26	.30	.04	.69
		11	2	.10	.07	.10	.06	.15
		MS	4	.08	.05	.06	.05	.15
		1,2,3-TMB	28-FEB-2004	2	2	.15	.03	.15
5	2			.05	.00	.05	.05	.05
6	2			.13	.05	.13	.09	.16
10	5			.18	.01	.18	.17	.20
11	2			.23	.01	.23	.23	.24
MS	4			.17	.08	.20	.05	.21
16-APR-2004	2		2	.14	.00	.14	.14	.15
	5		2	.05	.00	.05	.05	.05
	6		2	.05	.00	.05	.05	.05
	10		5	.08	.03	.10	.05	.11
	11		2	.11	.04	.11	.08	.14
	MS		4	.15	.02	.15	.13	.17
	p-Dichlorobenzene		28-FEB-2004	2	2	.07	.01	.07
5		2		.06	.00	.06	.06	.06
6		2		.18	.04	.18	.15	.21
10		5		1.45	1.69	1.39	.06	4.21
11		2		.48	.27	.48	.29	.67
MS		4		.34	.22	.33	.08	.61
16-APR-2004		2	2	.30	.07	.30	.25	.34
		5	2	.14	.11	.14	.06	.22
		6	2	1.15	.63	1.15	.70	1.59
		10	5	1.29	1.55	.21	.12	3.27
		11	2	.04	.02	.04	.03	.05
		MS	4	.19	.16	.19	.02	.36

Figure 1. Layout of House A7 with OVM Sample Positions and Compass Directions.

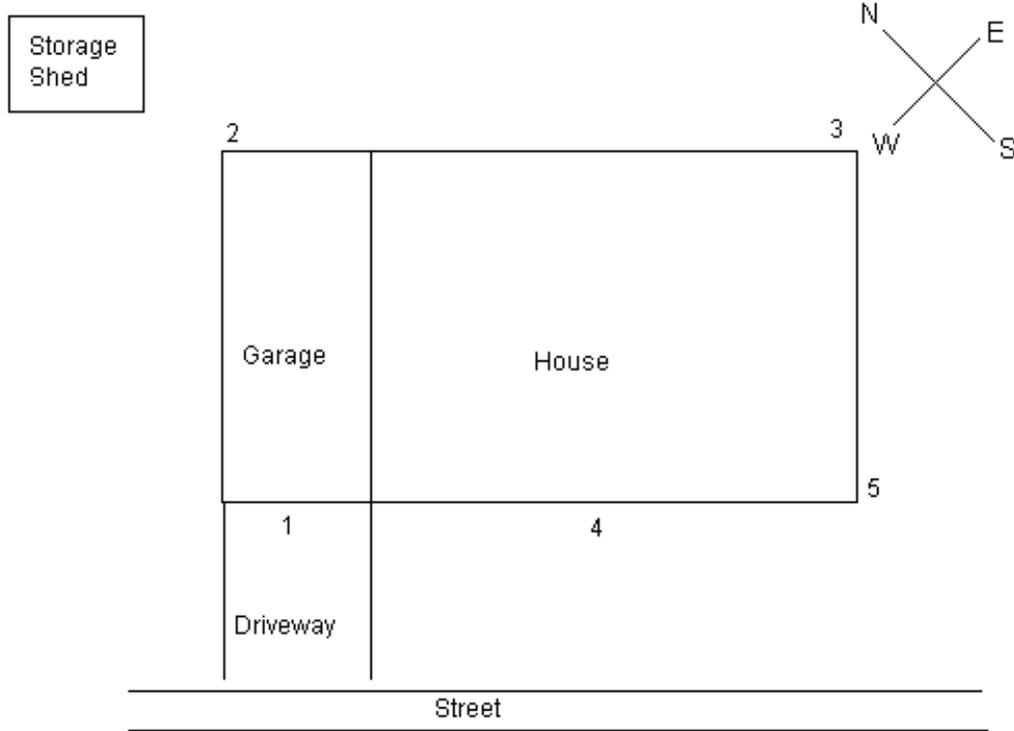
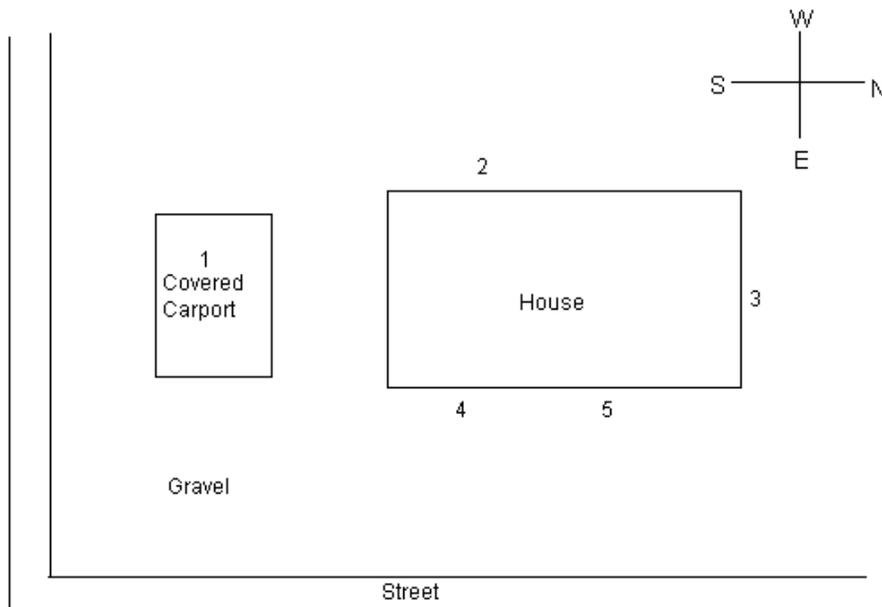


Figure 2. Layout of House C10 with OVM Sample Positions and Compass Directions.



Appendix A

Clinton Drive Monitoring Site

(Clinton C403/C113/C304)

- EPA site number: 48-201-1035
- Maintained by: City of Houston
- Address: 9525 1/2 Clinton Drive
 - City: Houston
 - County: Harris
 - Site coordinates:
 - Latitude: 29° 43' 59" North
 - Longitude: 95° 15' 24" West

- Real-time monitoring since: Wednesday, December 17, 1997
- Current status: Active
- Parameters currently being monitored:
 - Pollution parameters:
 - Carbon Monoxide
 - Sulfur Dioxide
 - Nitric Oxide
 - Nitrogen Dioxide
 - Oxides of Nitrogen
 - Ozone
 - PM-2.5 (Local Conditions)
 - Meteorological parameters:
 - Wind Speed
 - Resultant Wind Speed
 - Resultant Wind Direction
 - Maximum Wind Gust
 - Standard Deviation of Horizontal Wind Direction
 - Outdoor Temperature
 - Relative Humidity
 - Solar Radiation
 - Ultraviolet Radiation
 - Precipitation

View of the Clinton Drive monitoring trailer.



View from the Clinton Drive trailer looking east.



Appendix B

Phase III

Maps Showing Locations of Three Monitoring Areas

Figure A-1. Houston Regional Air Monitoring Sites

Figure A-2. Aldine CAMS

Figure A-3. Clinton CAMS

Figure A-4. Deer Park CAMS

Figure B-1. Sampling Boundaries with TRI Sources

Figure B-2. Sampling Boundaries for Aldine Area

Figure B-3. Sampling Boundaries for Clinton Area

Figure B-4. Sampling Boundaries for Deer Park Area

Figure A-1. Houston Regional Air Monitoring Sites

Aldine = C08
Clinton Drive = C403
Deer Park = C35

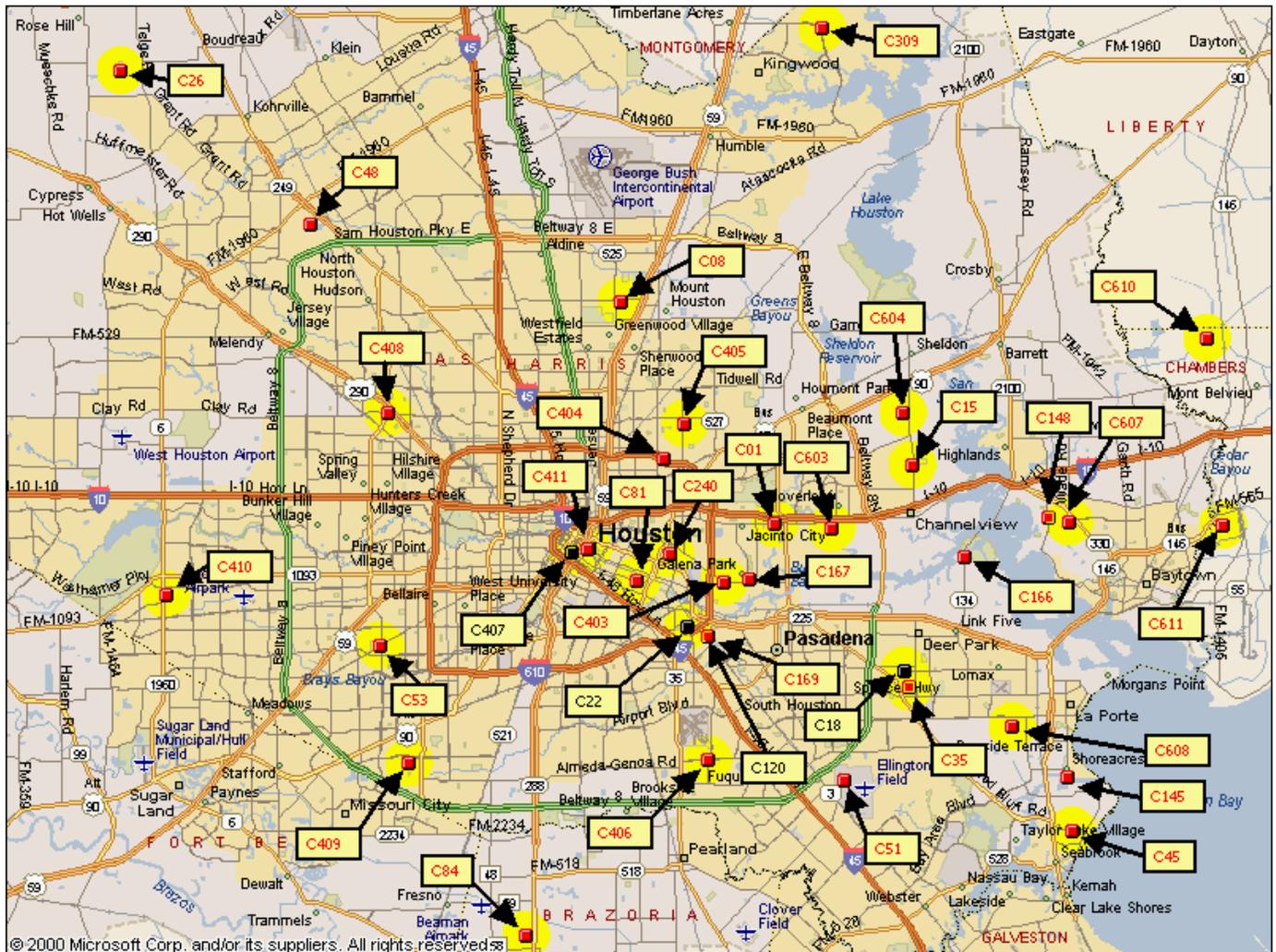


Figure A-2. Aldine CAMS

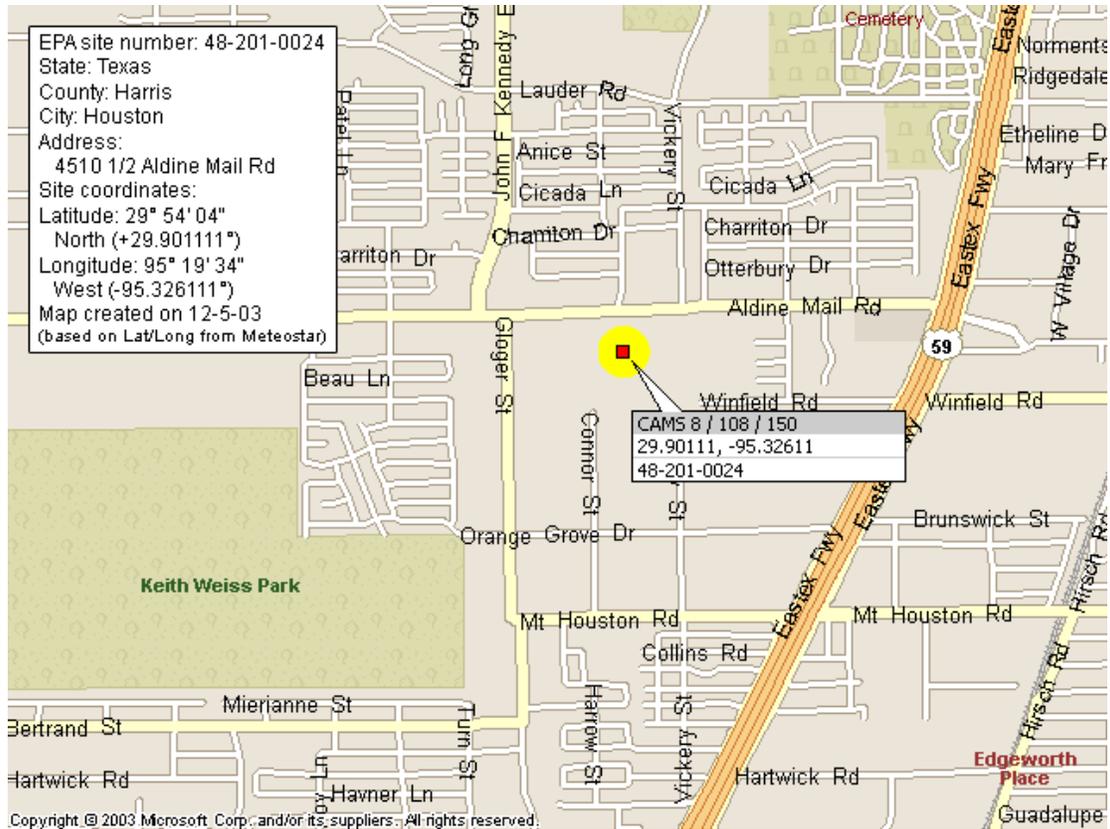


Figure A-3. Clinton Drive CAMS

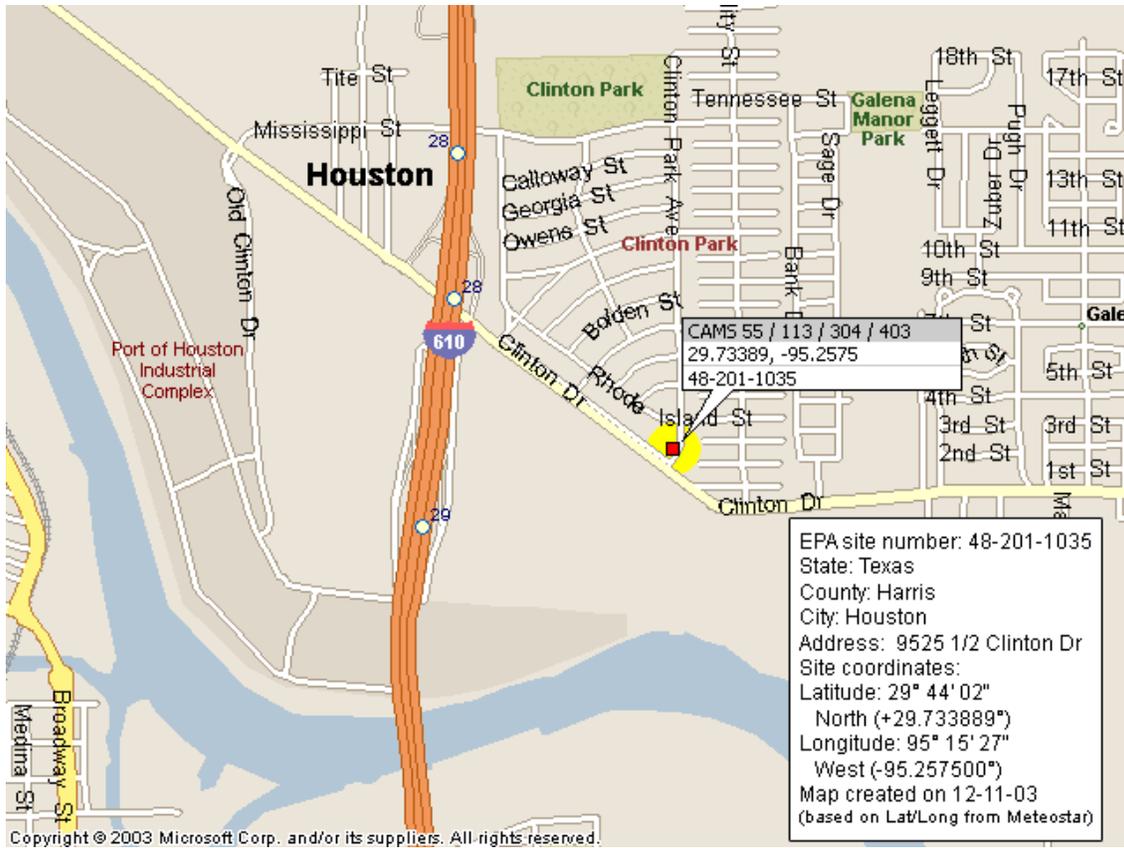


Figure A-4. Deer Park #2 CAMS

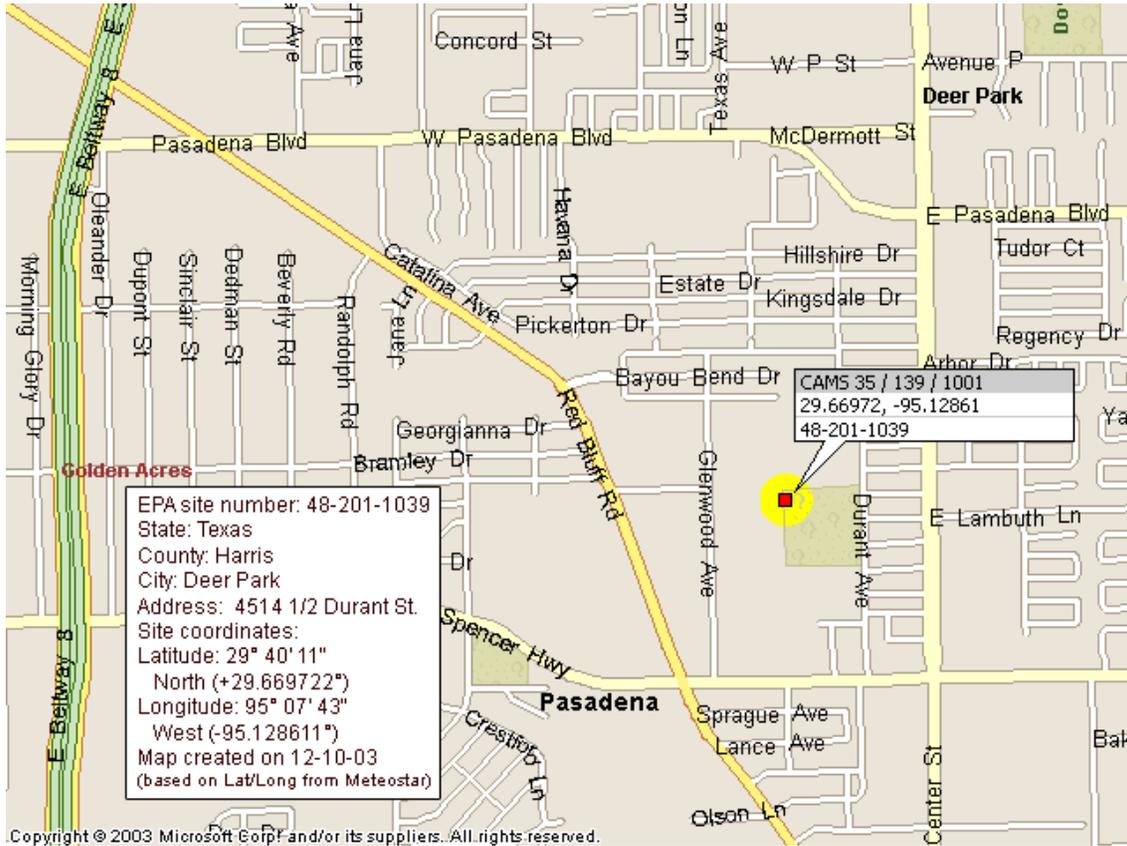


Figure B-1. Sampling Boundaries (TRI sources in green circle)

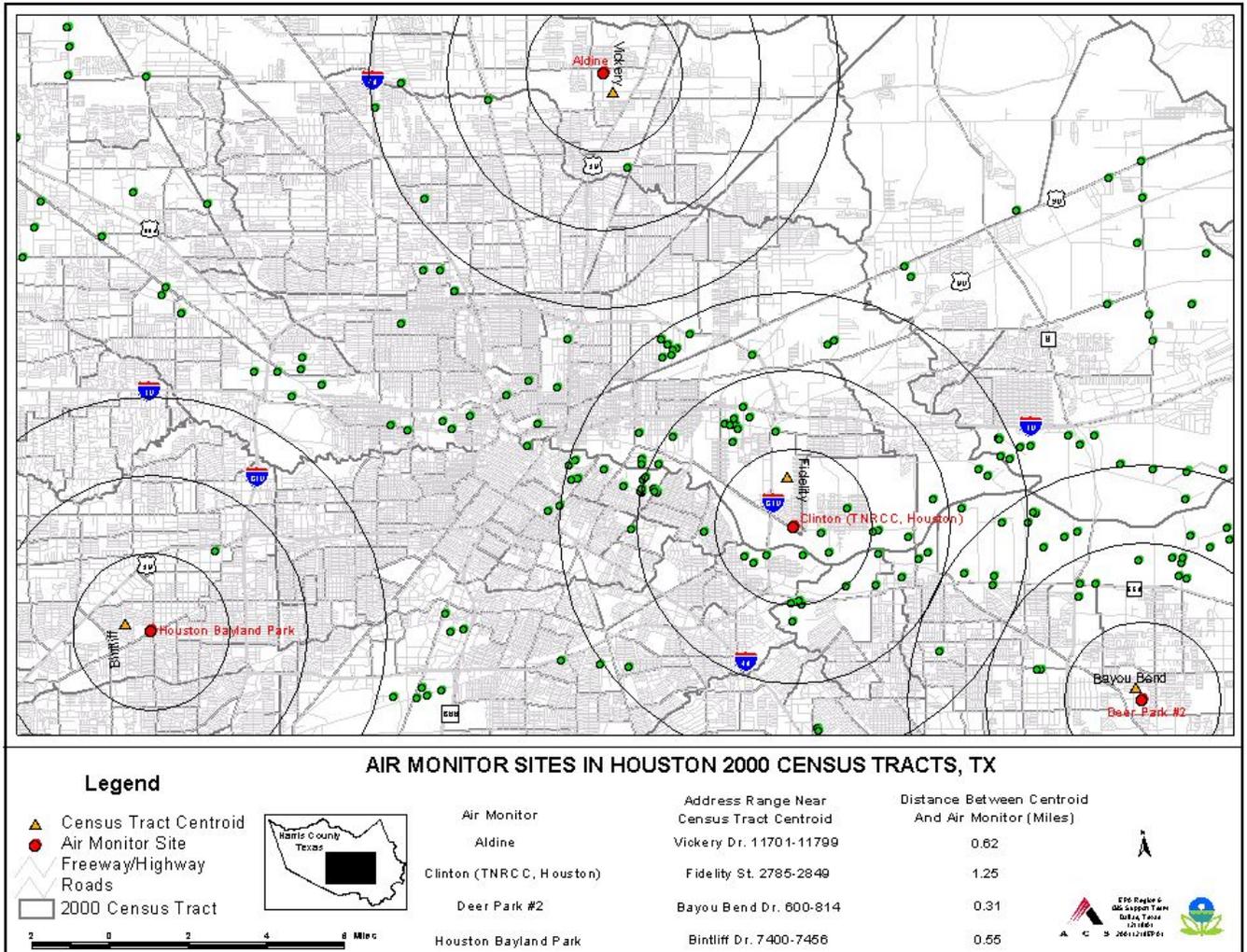


Figure B-2. Sampling Boundaries - Aldine Area

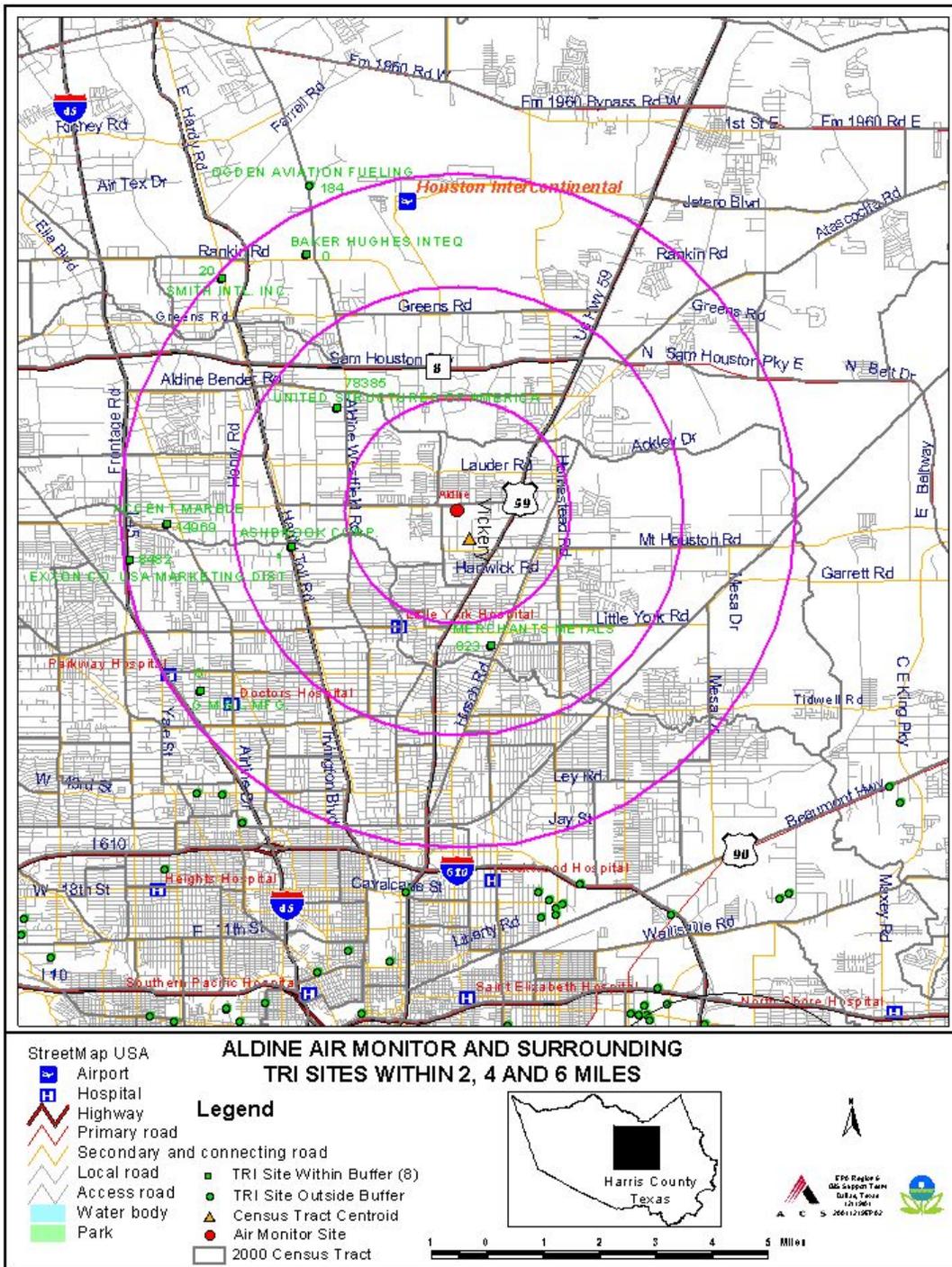
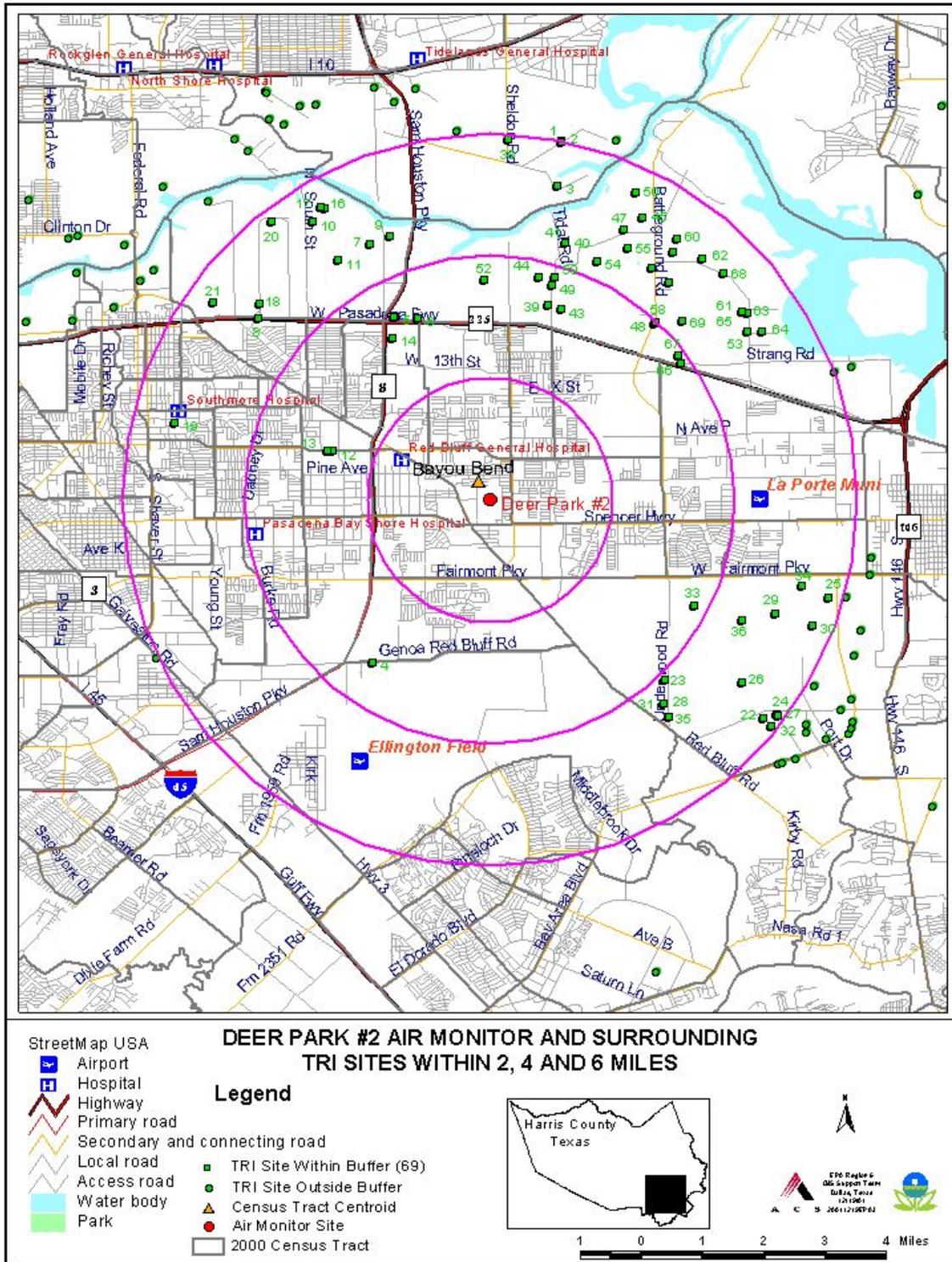


Figure B-4. Sampling Boundaries - Deer Park Area

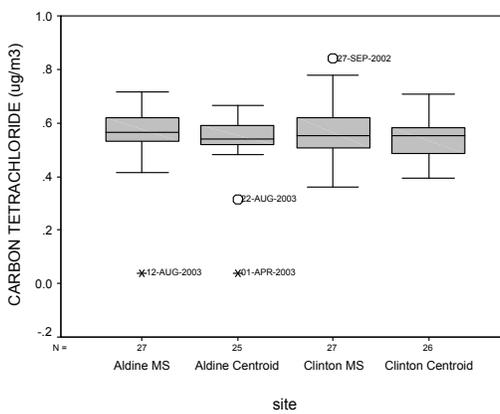
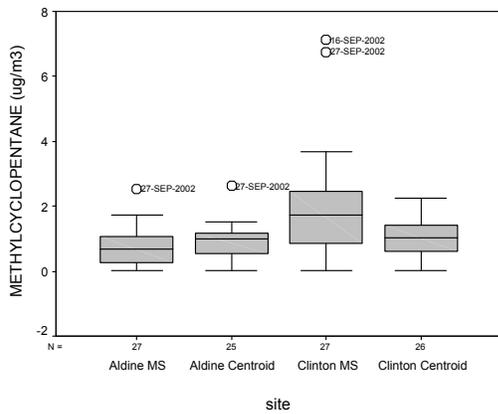
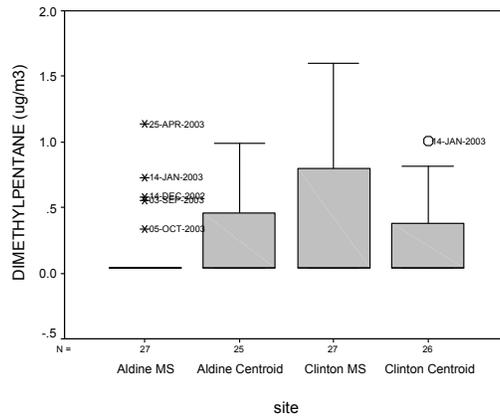
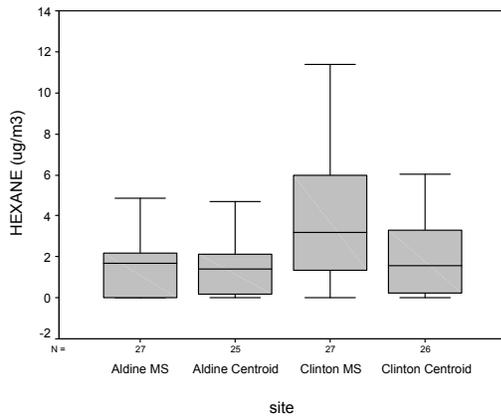
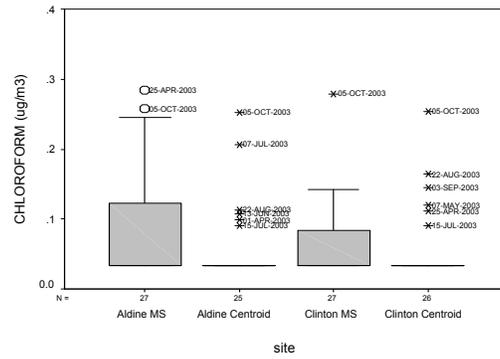
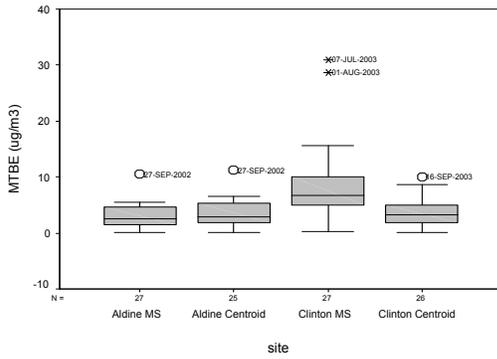
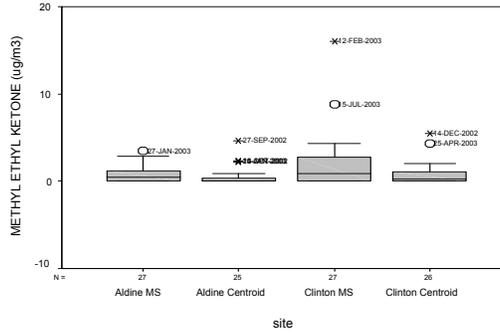
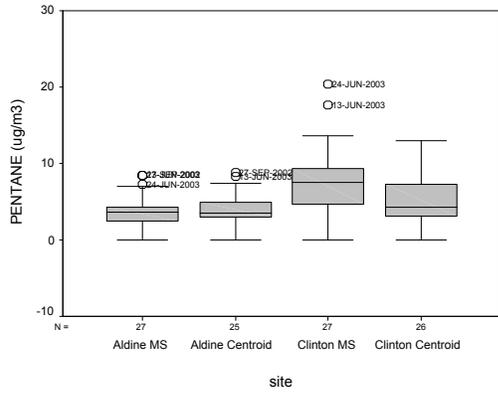


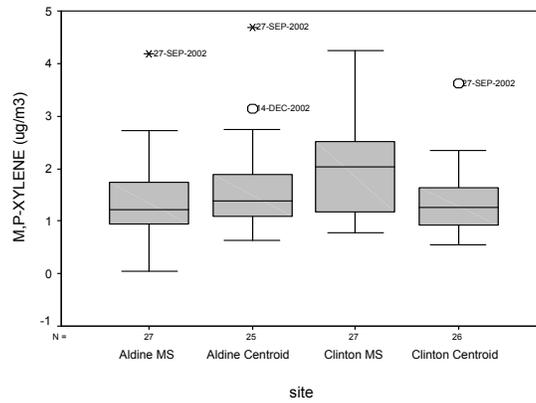
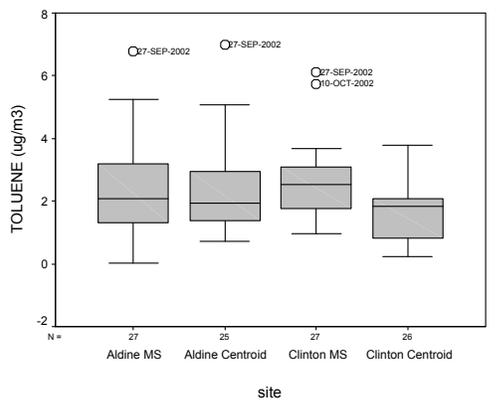
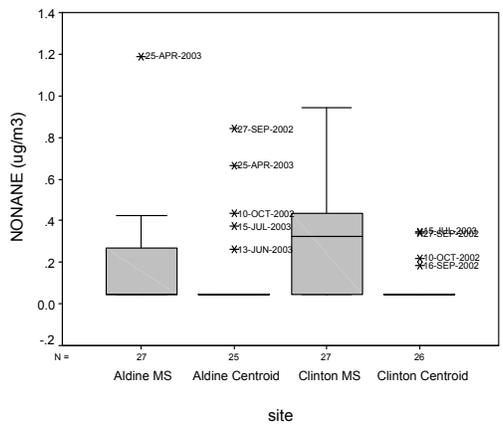
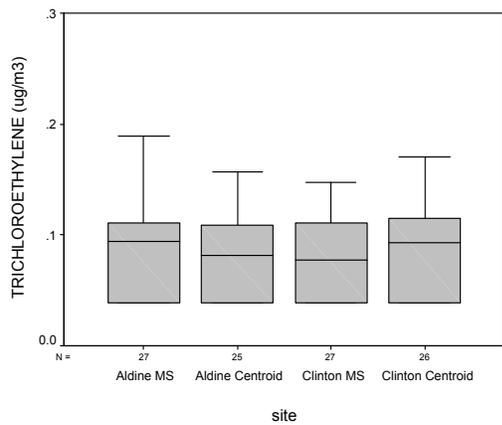
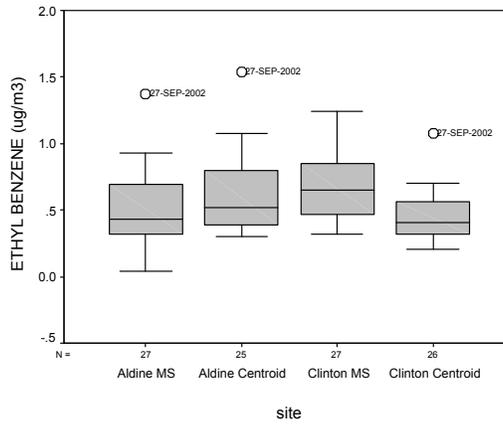
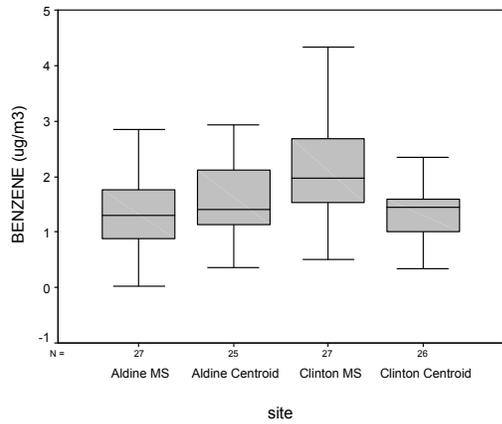
Appendix C

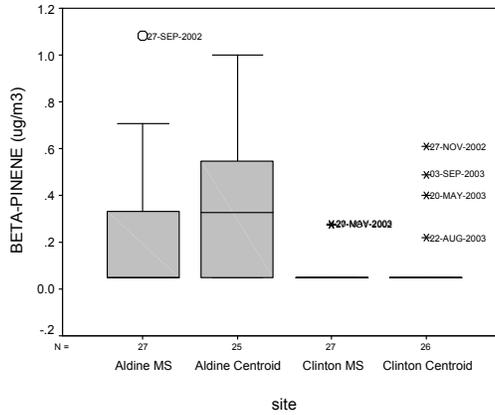
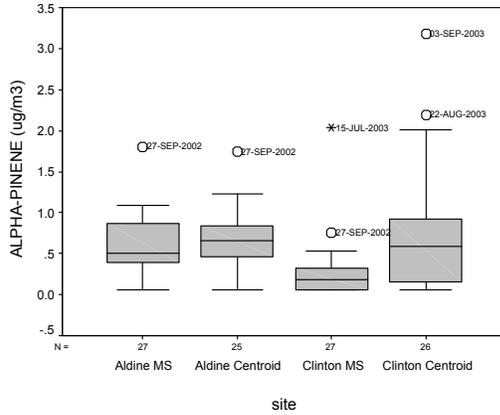
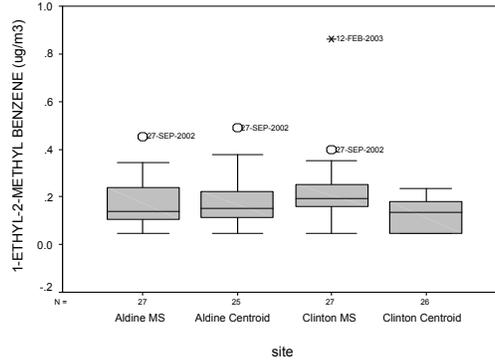
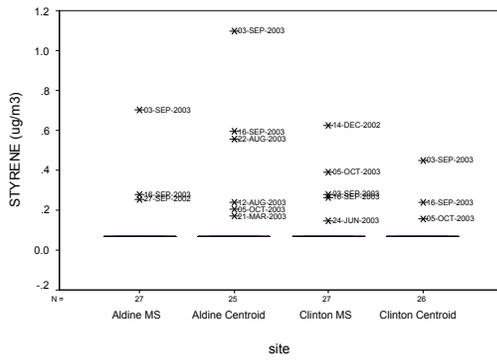
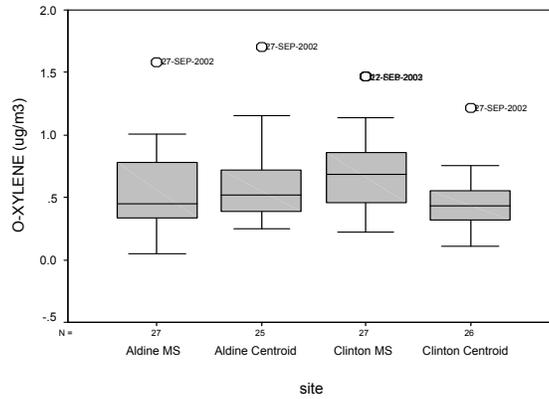
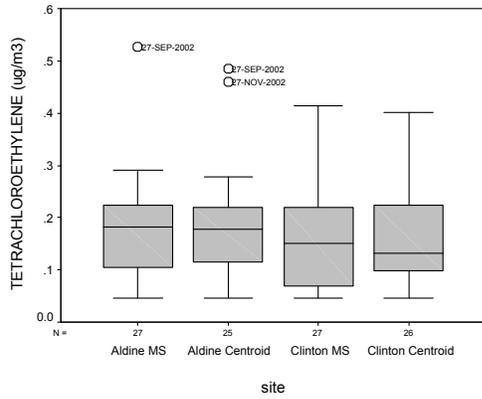
Phase II

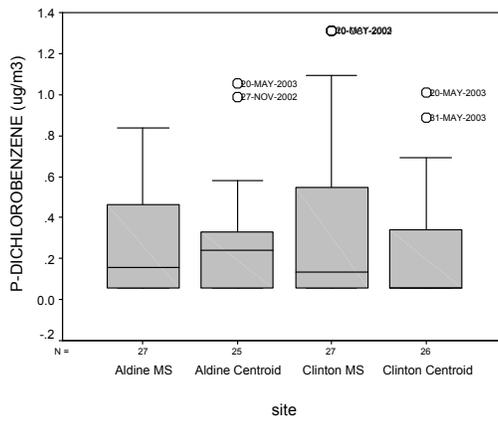
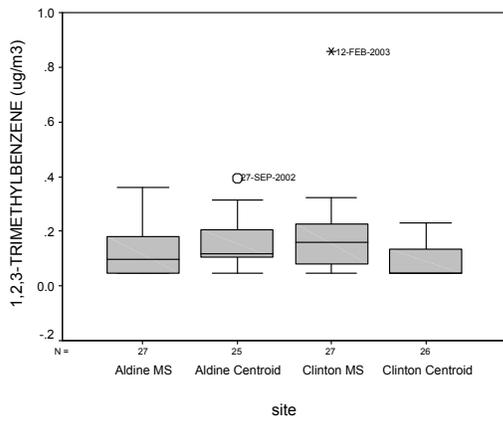
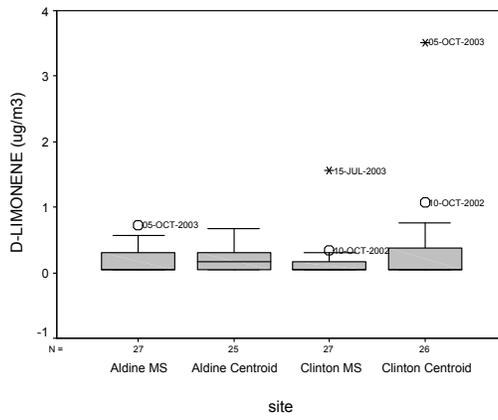
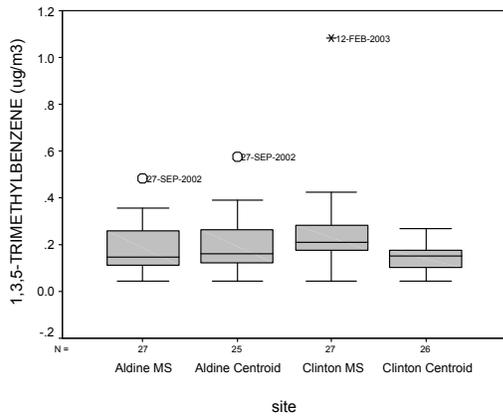
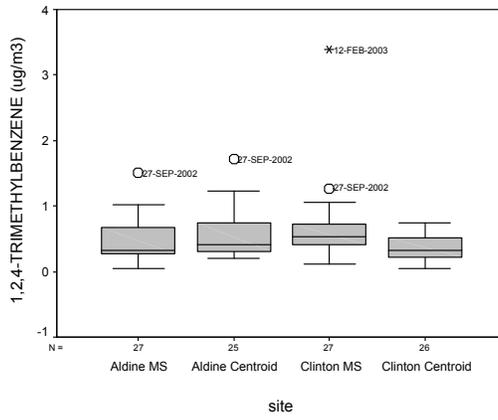
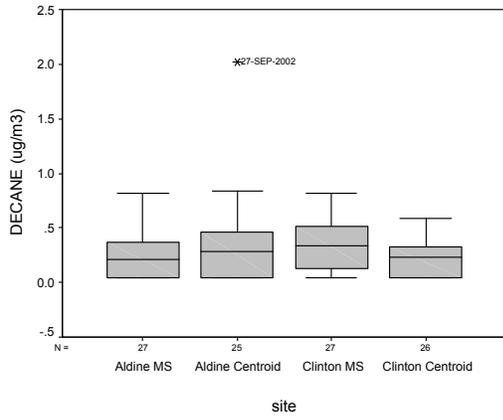
Box Plots of VOC Concentrations, by Site of Measurement

Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with an open circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.









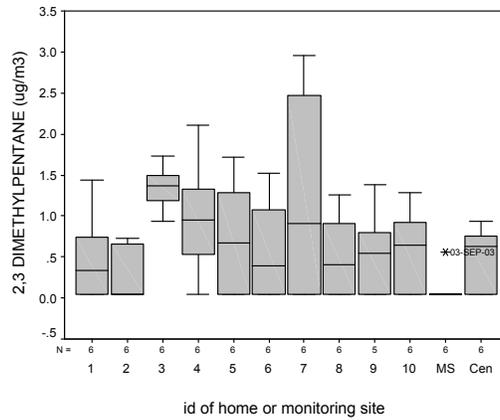
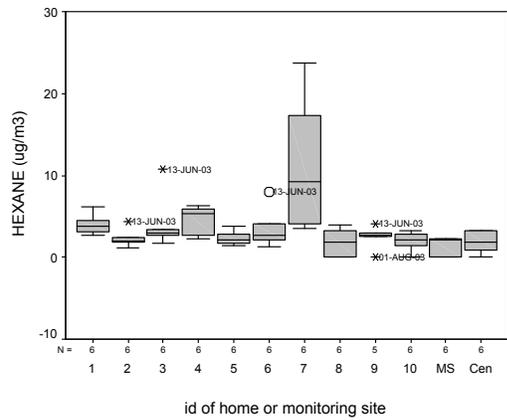
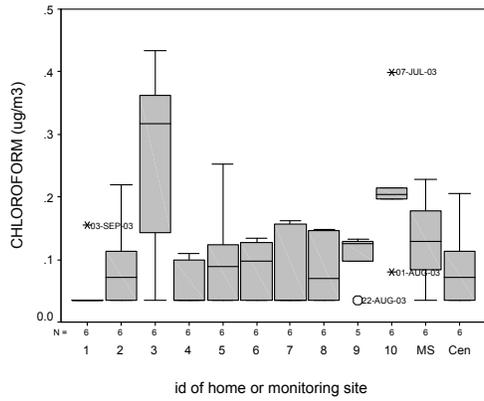
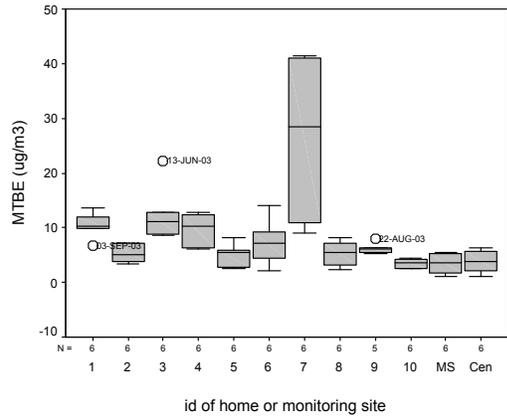
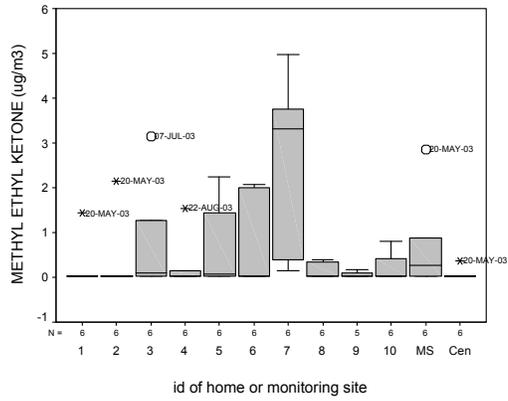
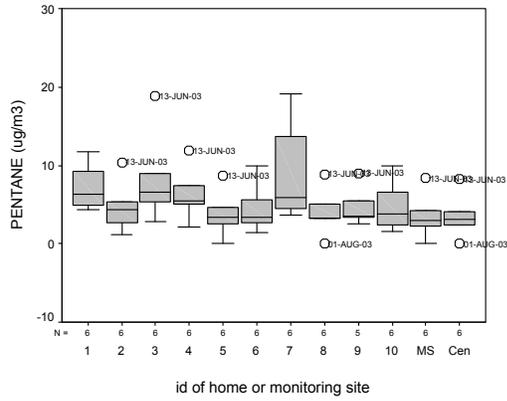
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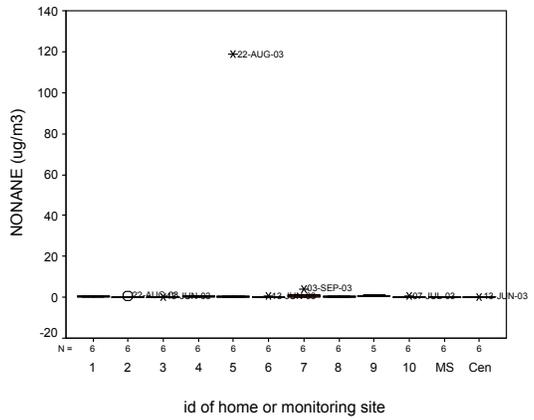
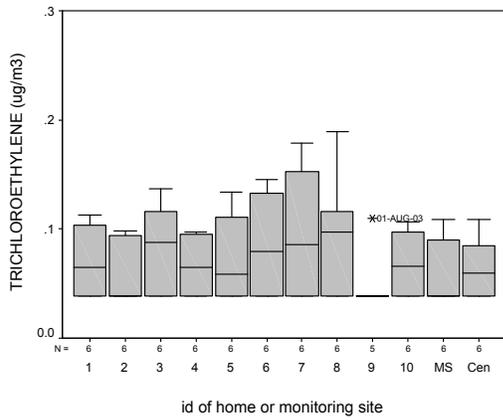
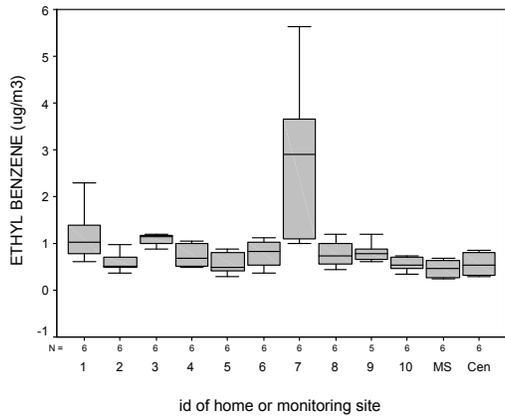
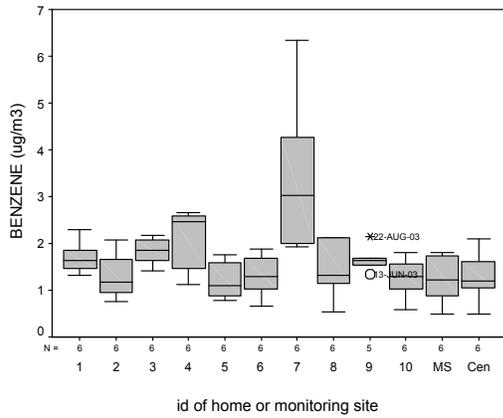
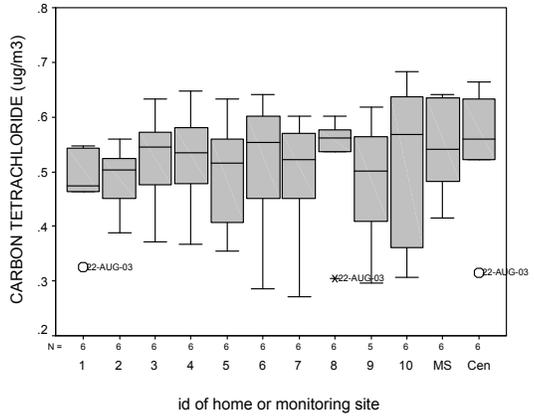
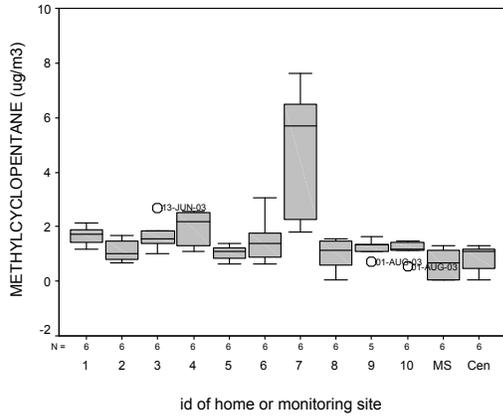
Phase III

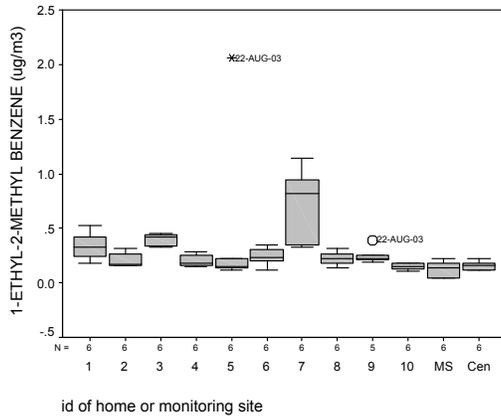
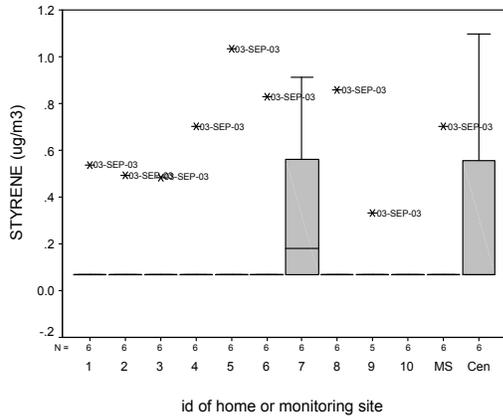
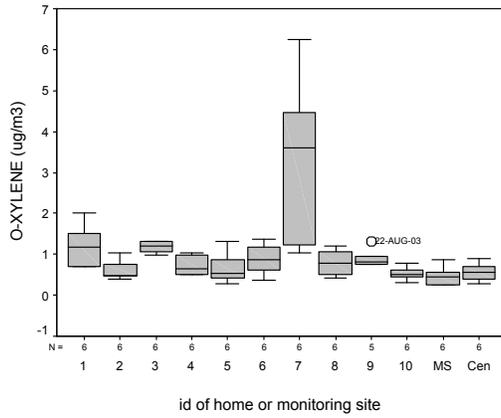
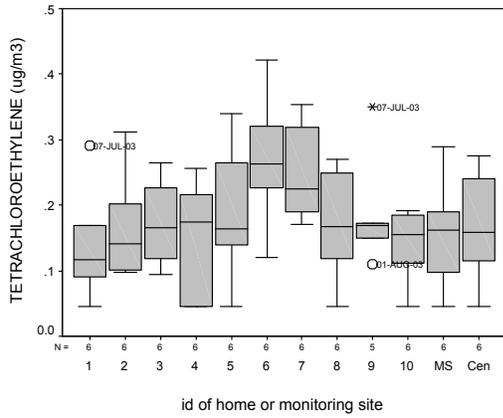
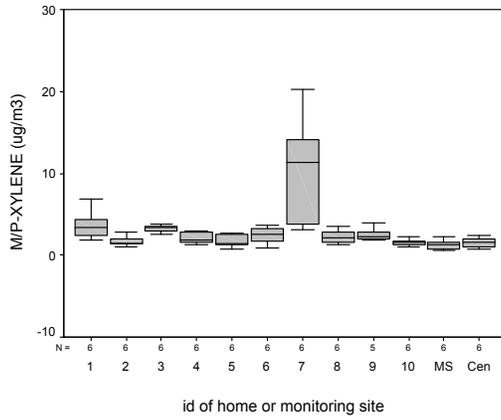
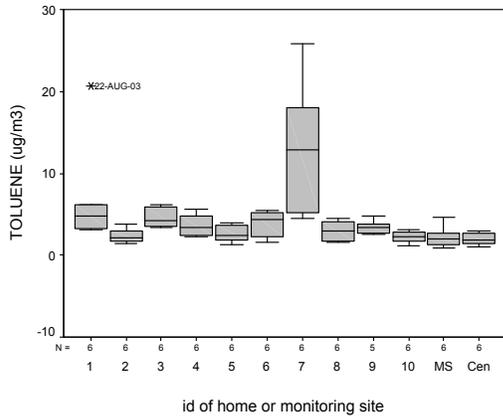
Box Plots of VOC Concentrations, by Site of Measurement for Phase III

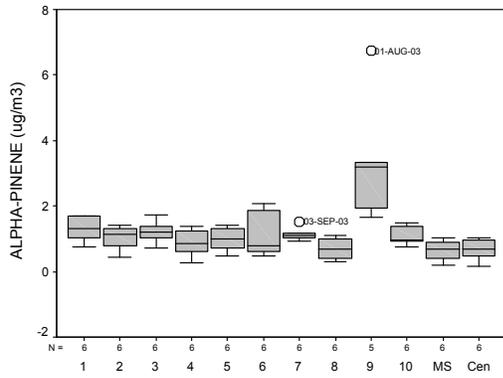
Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with an open circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

Aldine

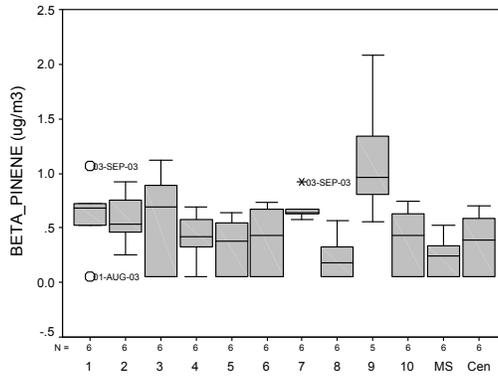




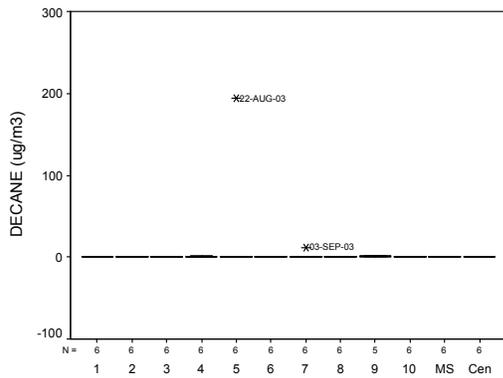




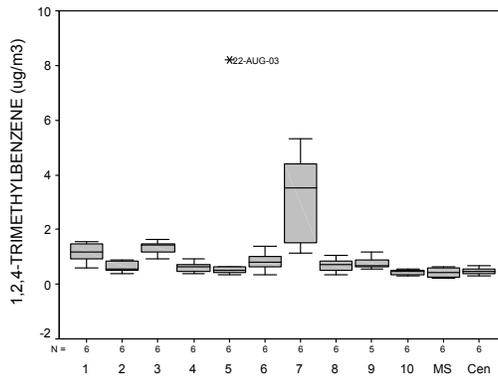
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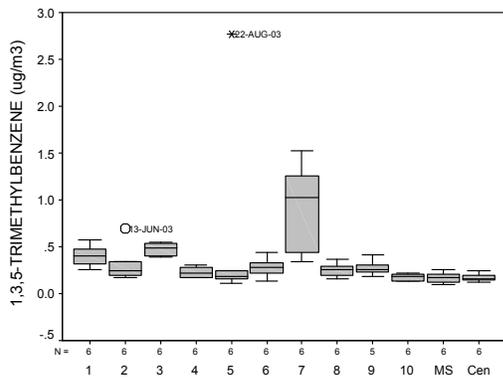
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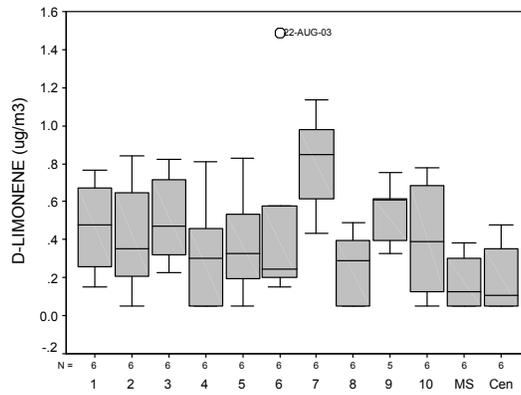
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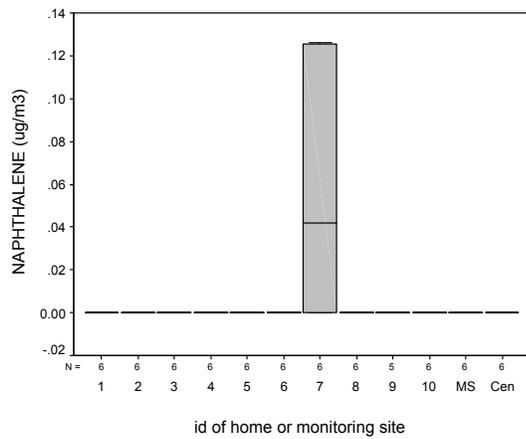
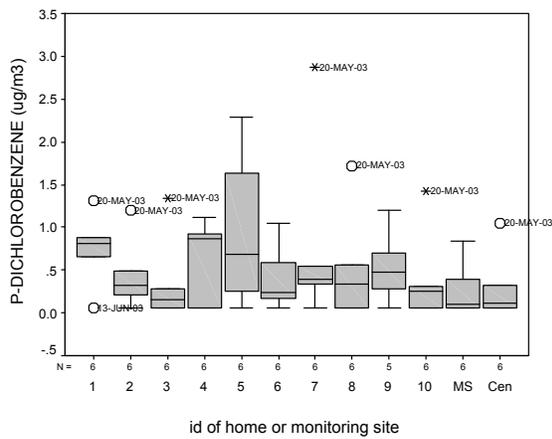
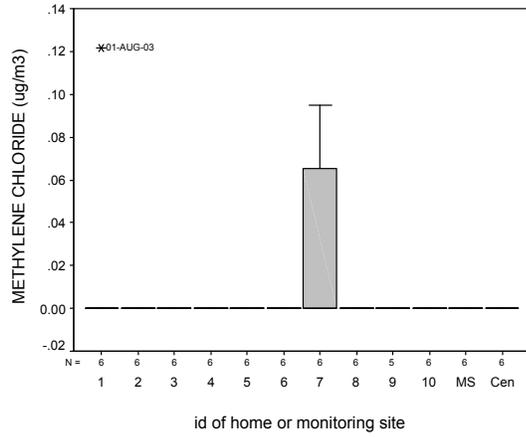
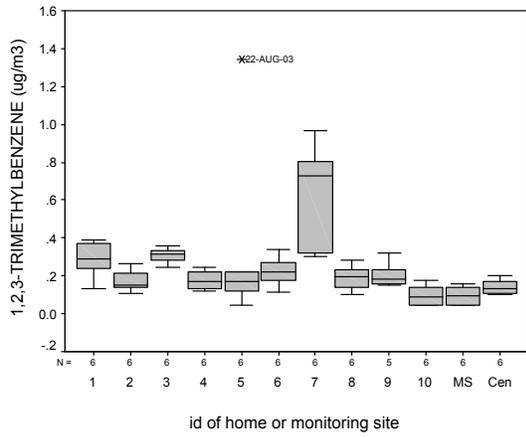
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id of home or monitoring site



id of home or monitoring site

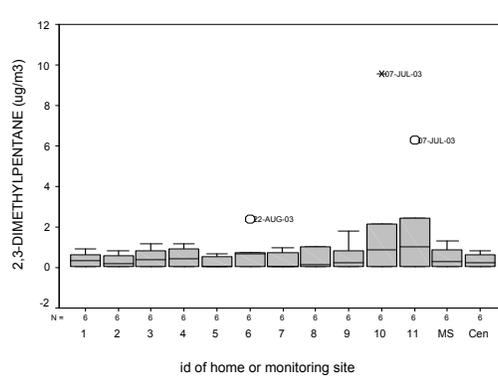
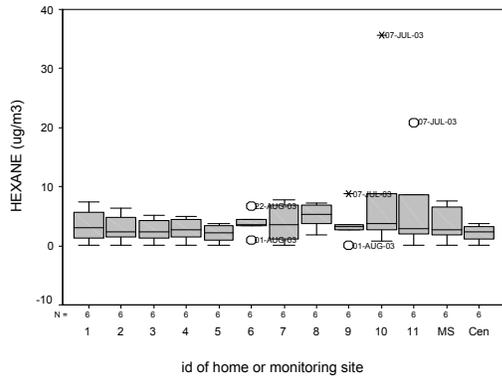
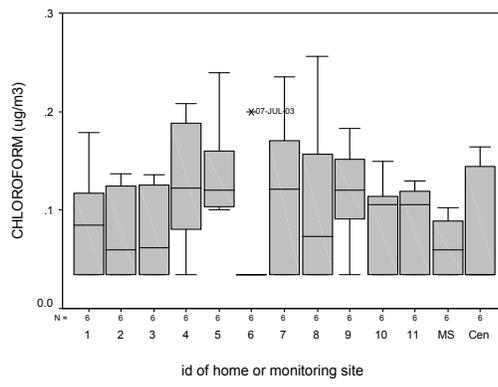
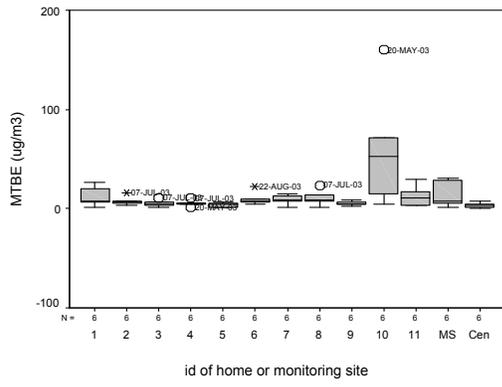
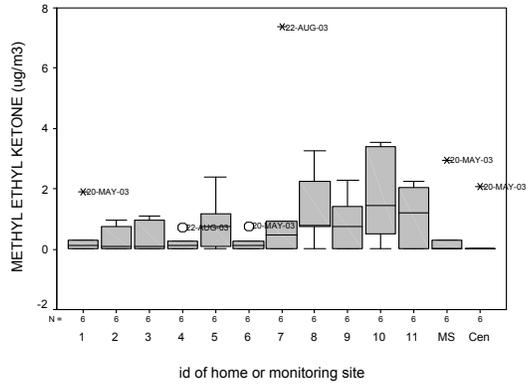
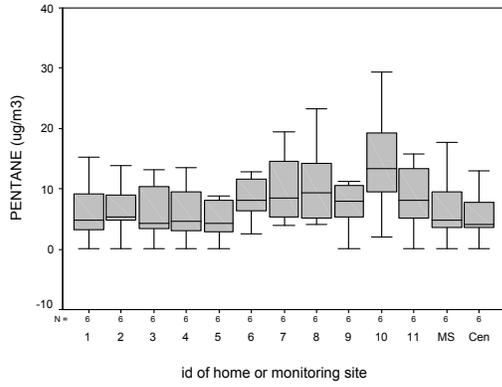


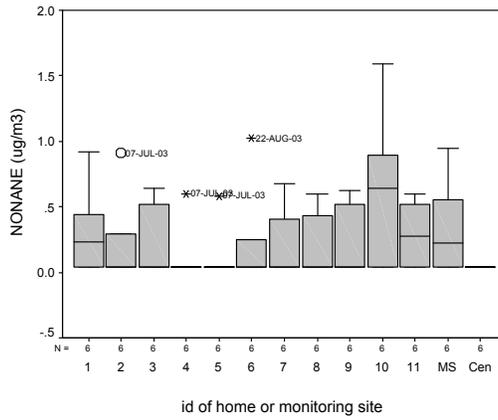
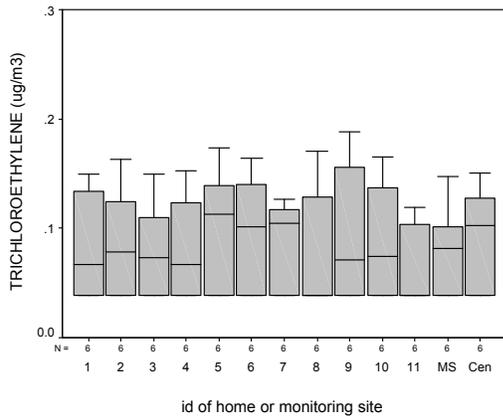
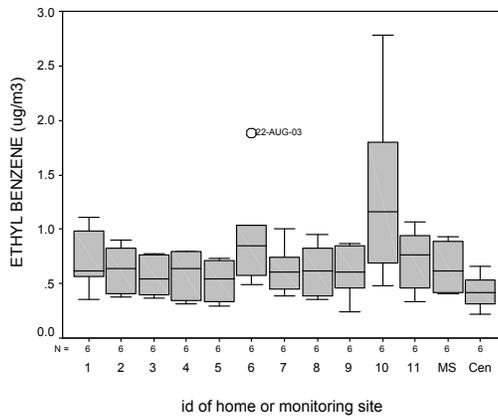
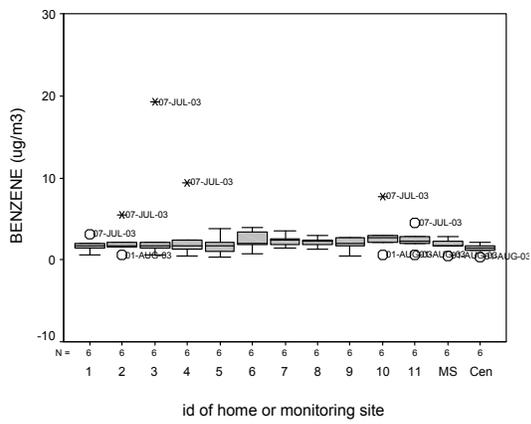
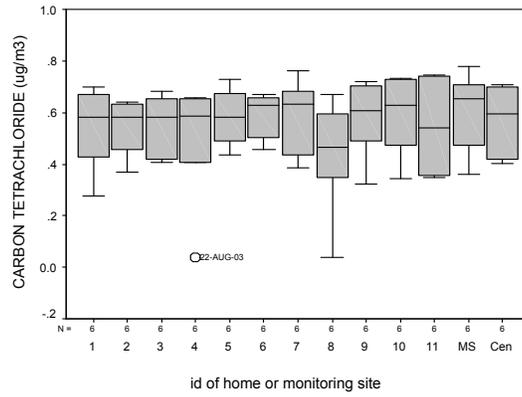
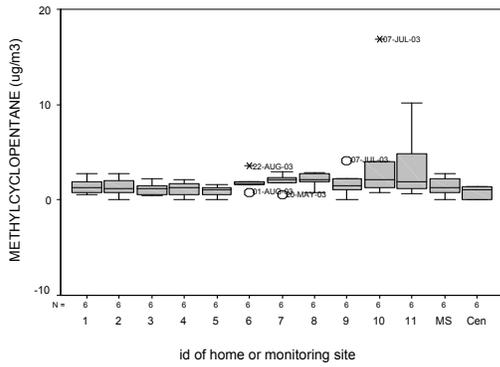
Appendix D

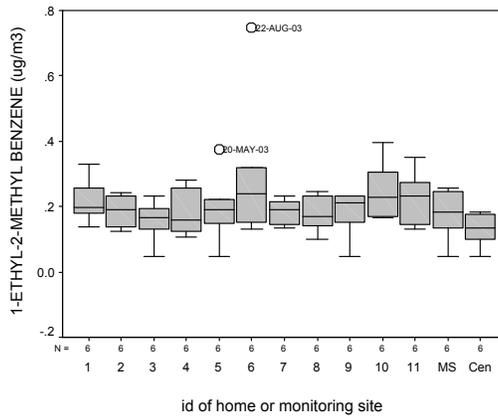
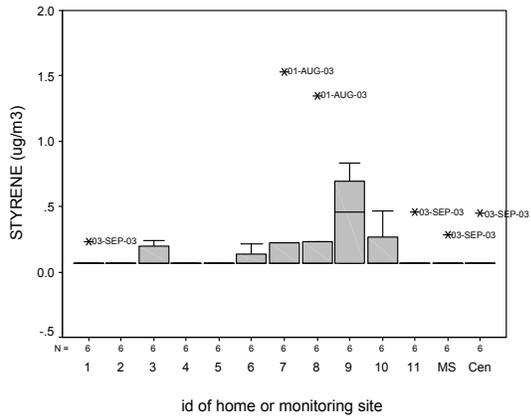
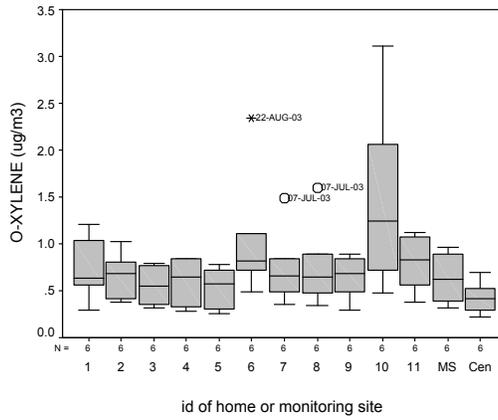
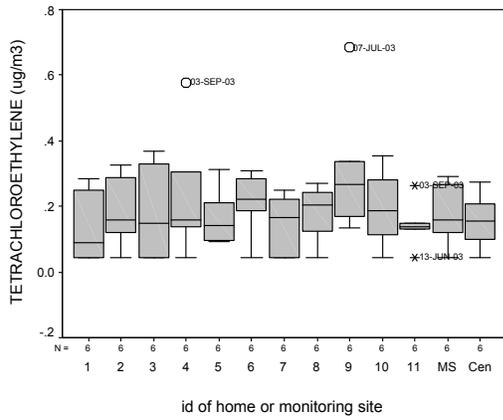
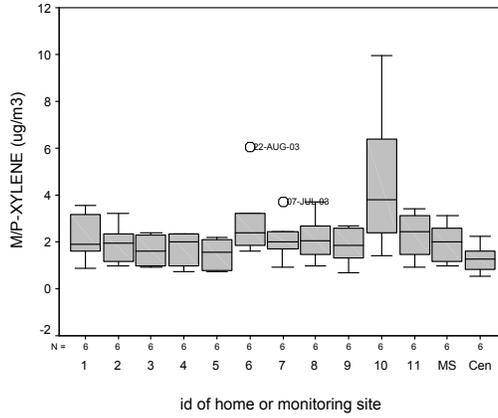
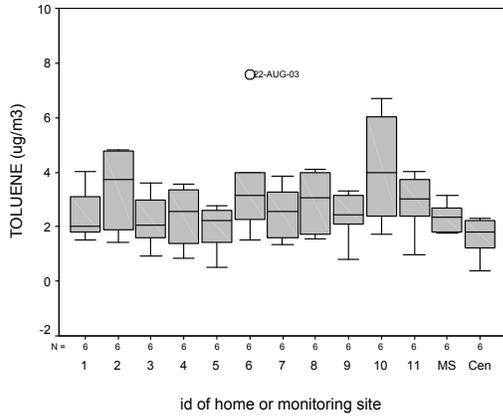
PHASE III

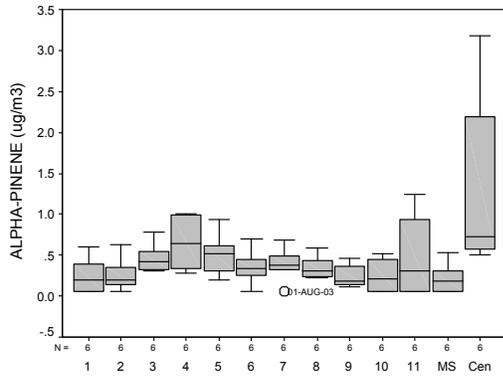
Box Plots of VOC Concentrations, by Site of Measurement for Phase III

Clinton

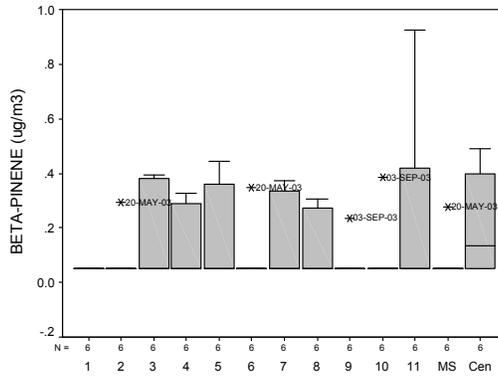




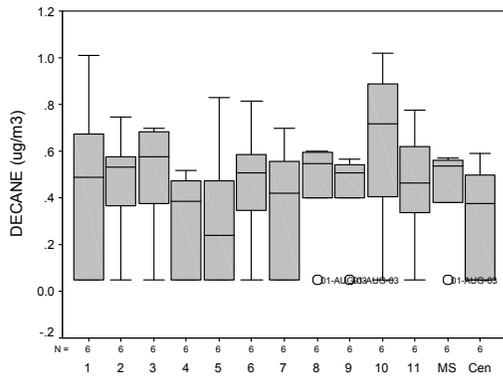




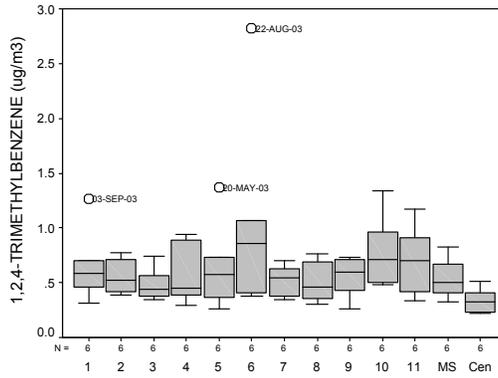
id of home or monitoring site



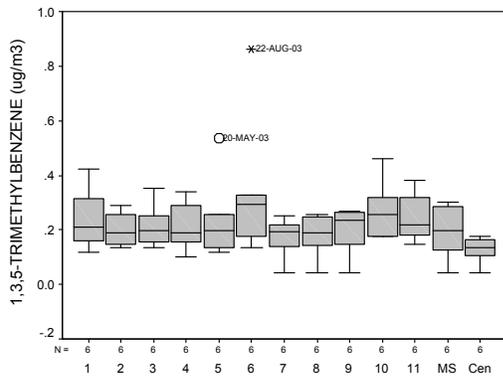
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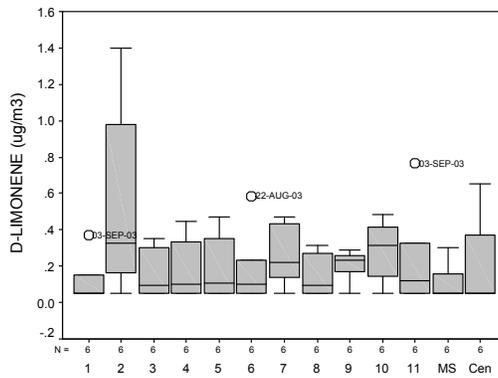
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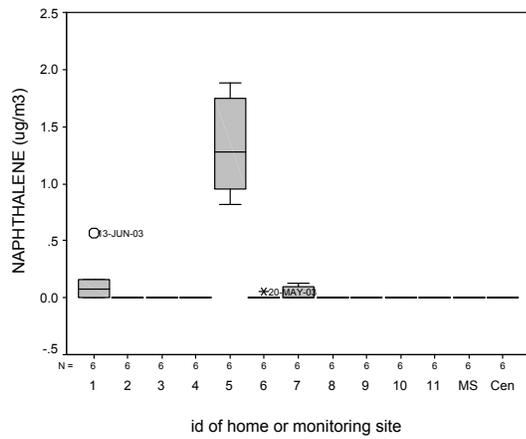
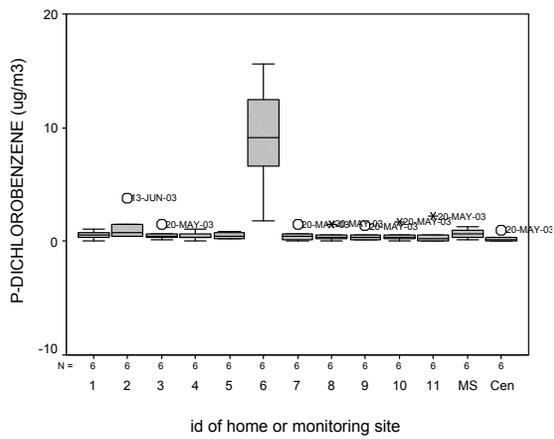
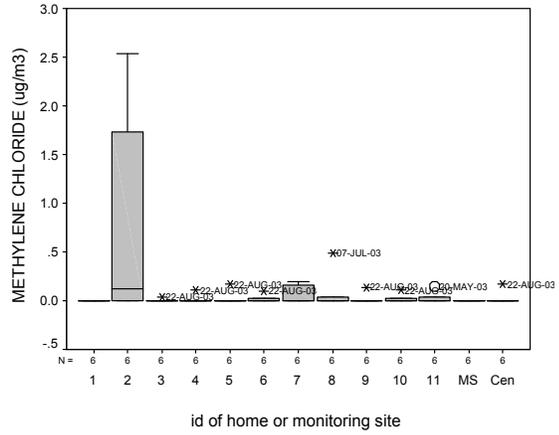
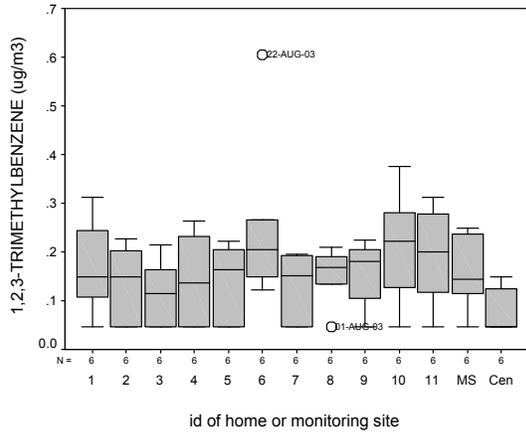
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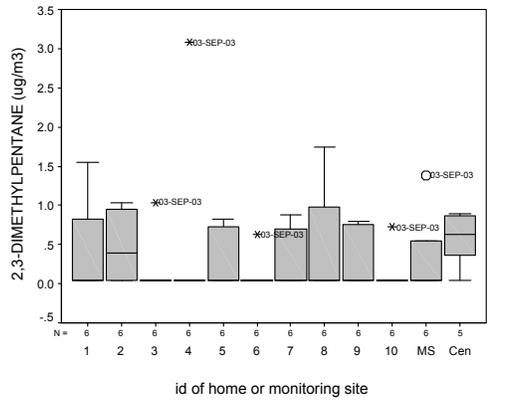
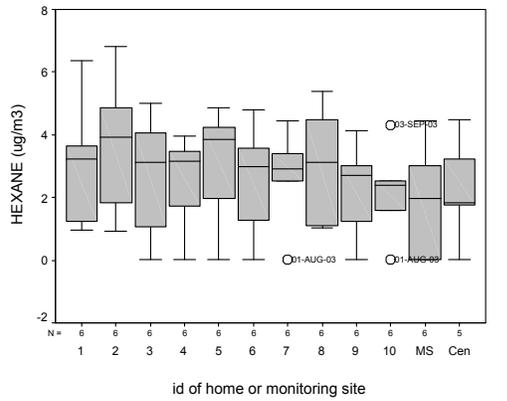
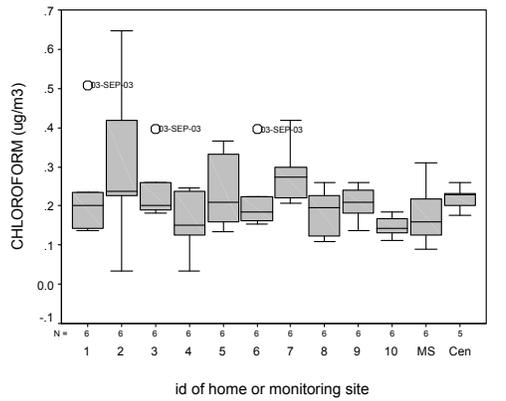
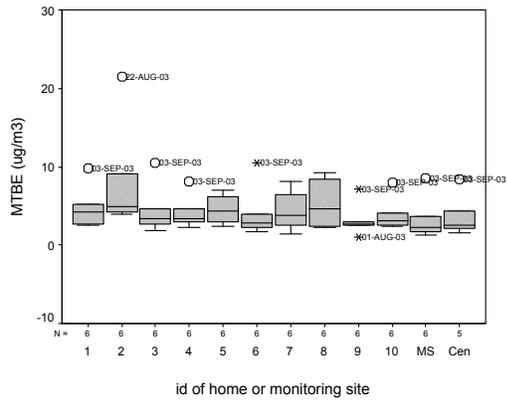
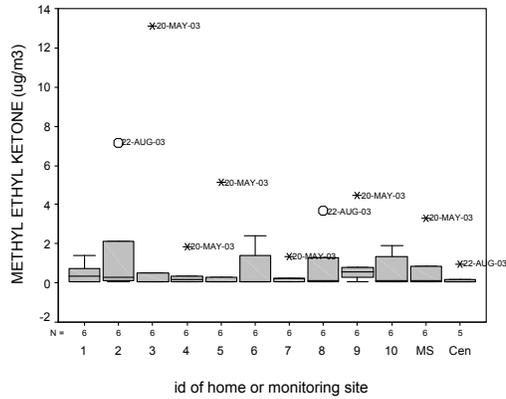
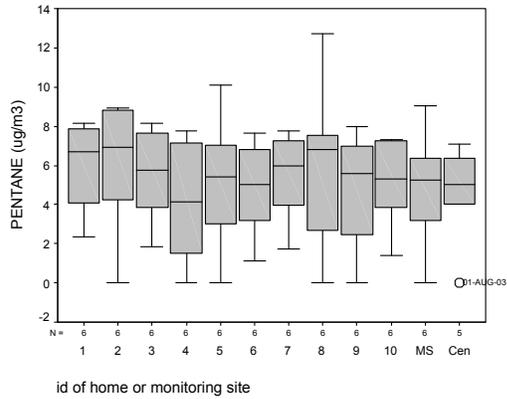


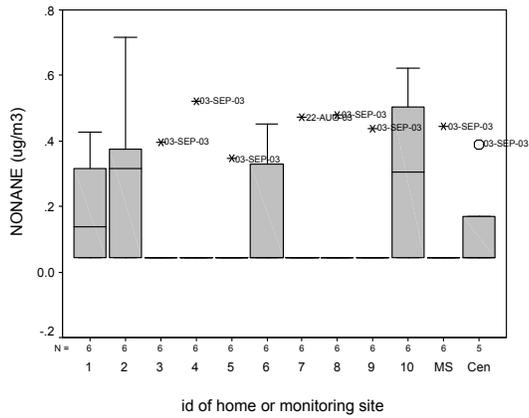
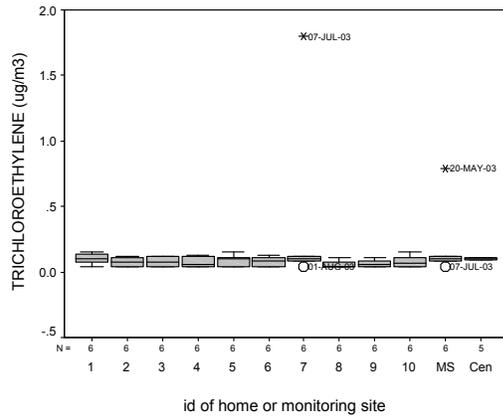
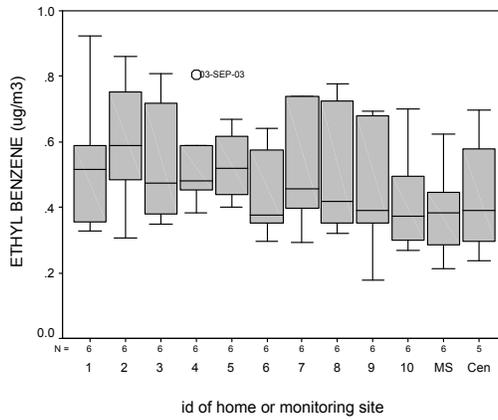
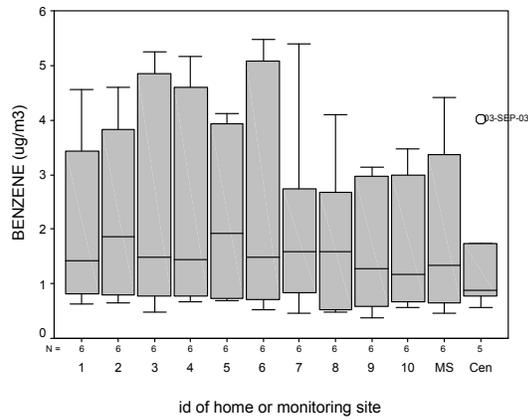
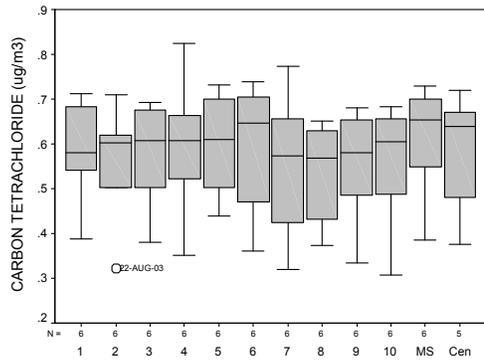
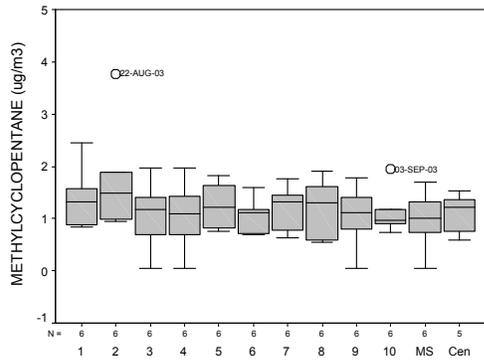
Appendix D

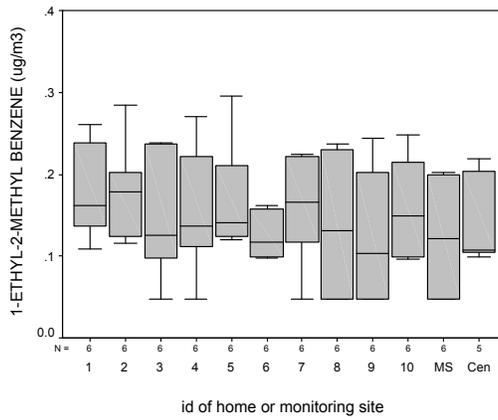
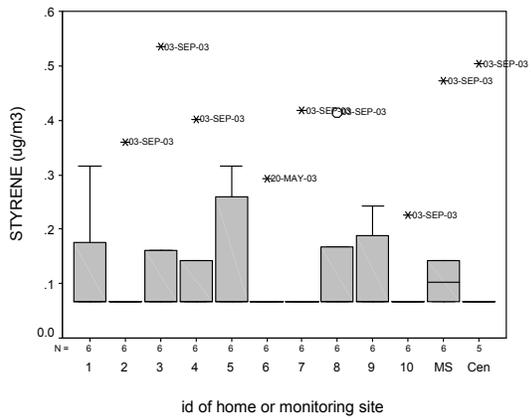
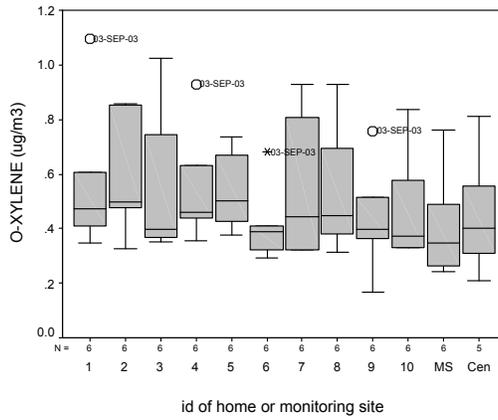
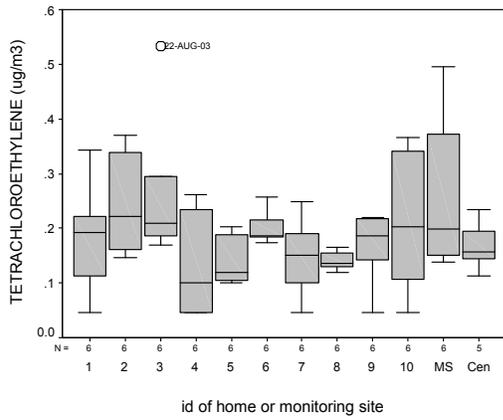
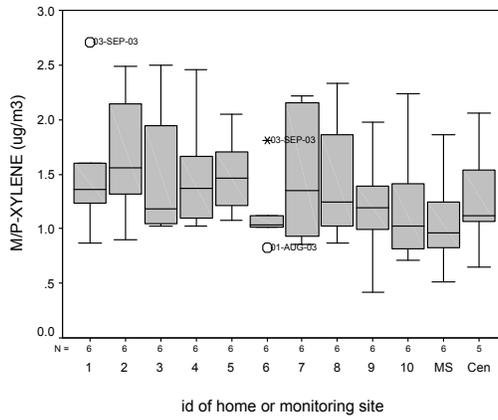
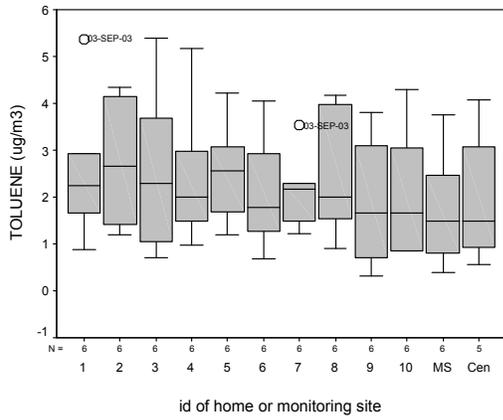
Phase III

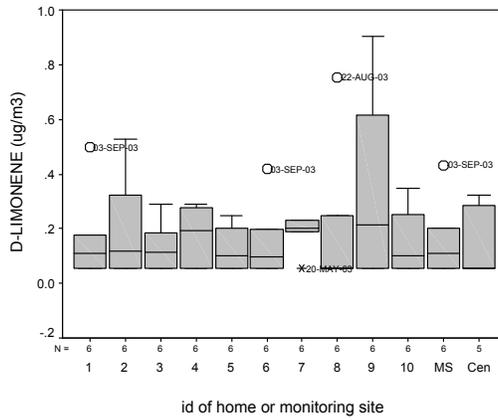
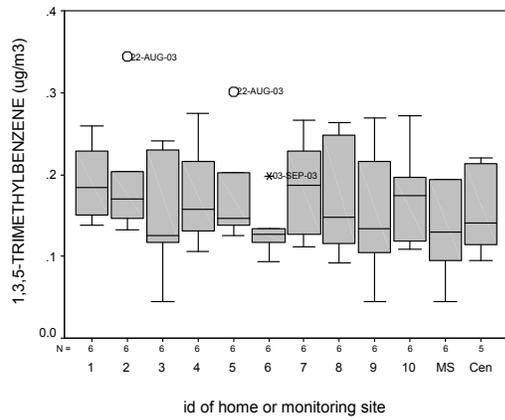
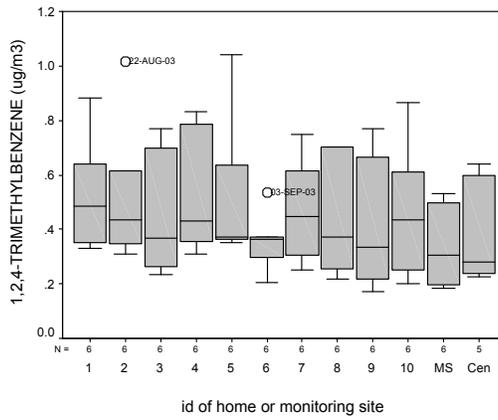
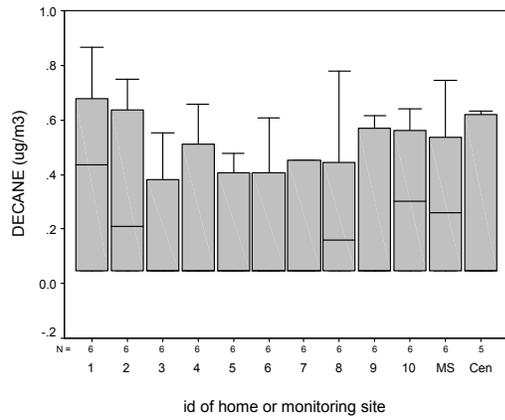
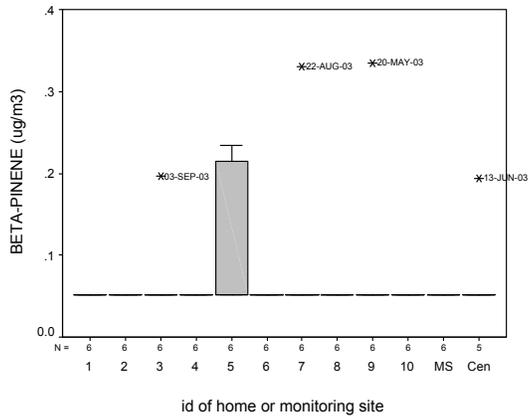
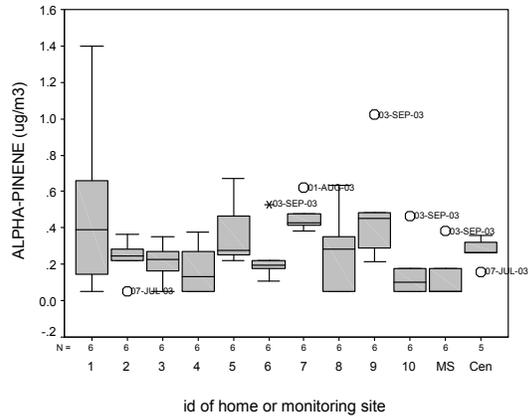
Box Plots of VOC Concentrations, by Site of Measurement for Phase III

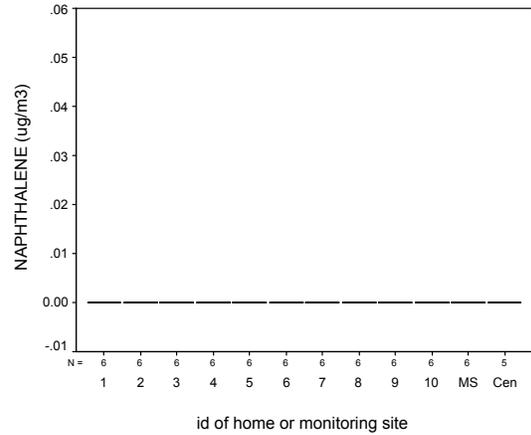
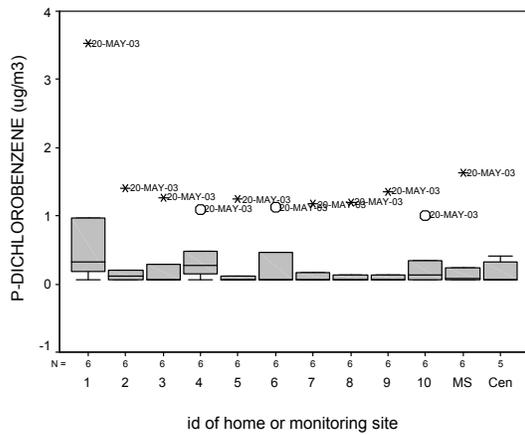
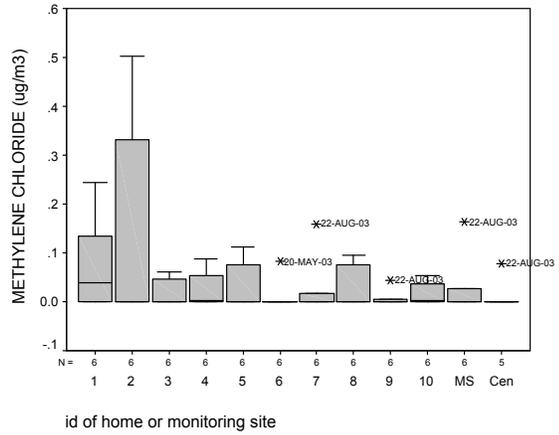
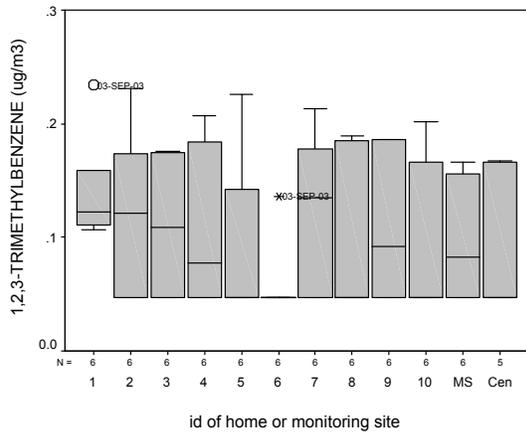
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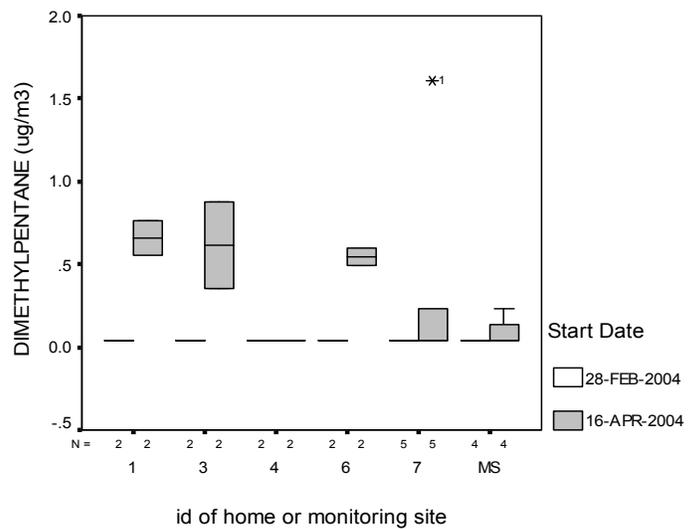
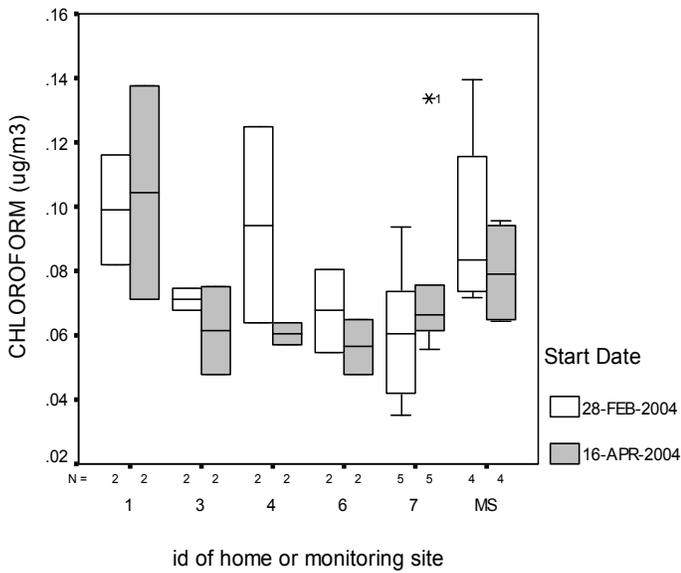
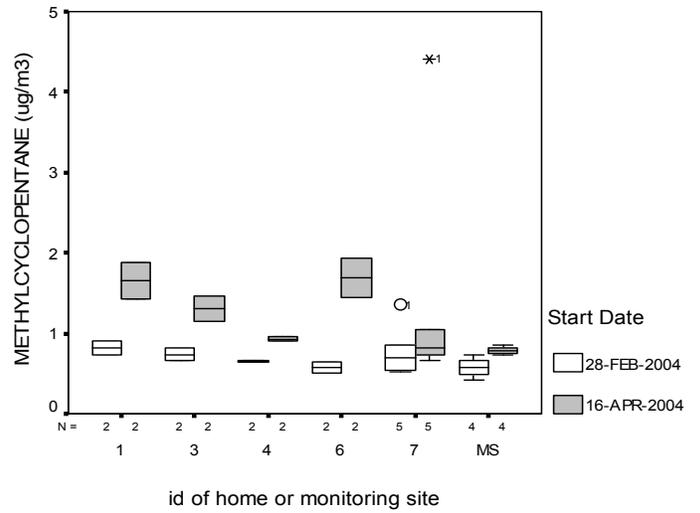
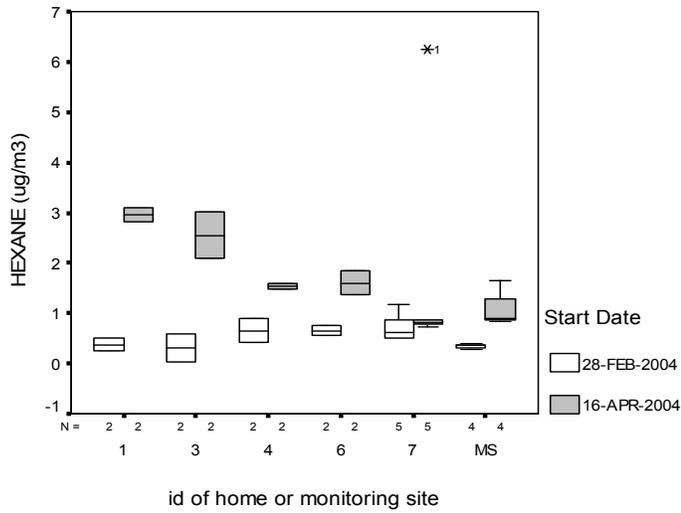
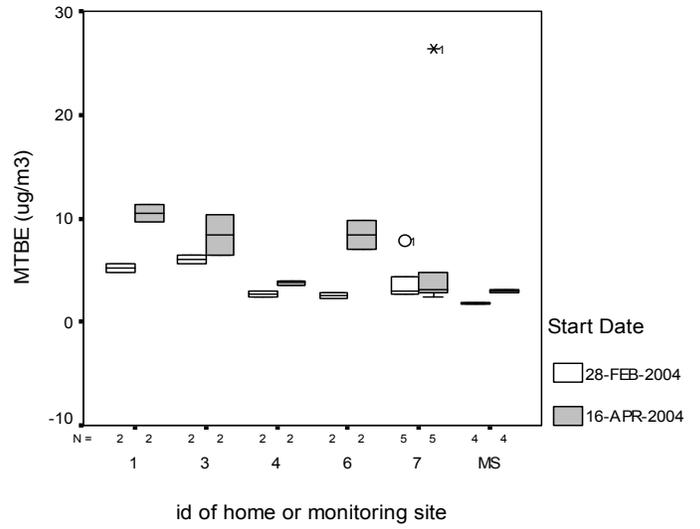
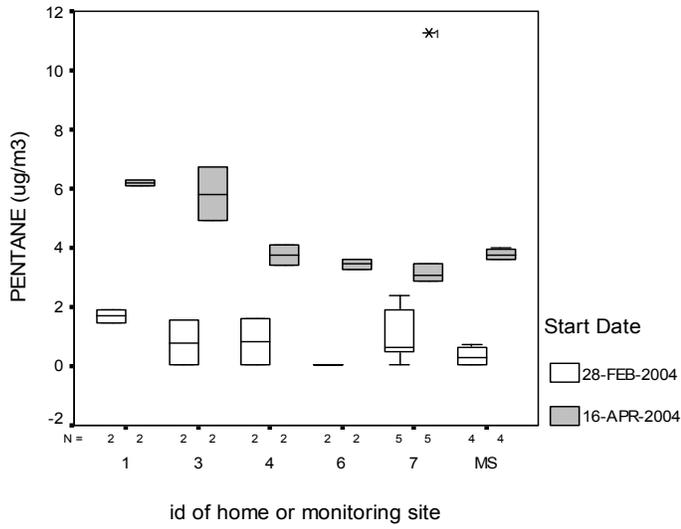


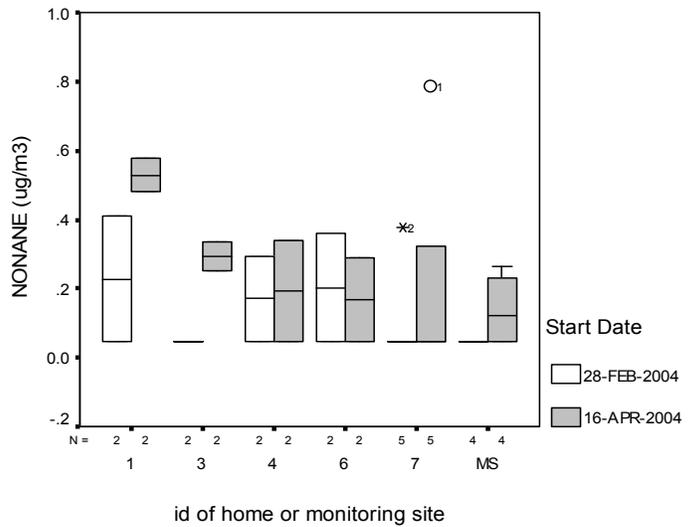
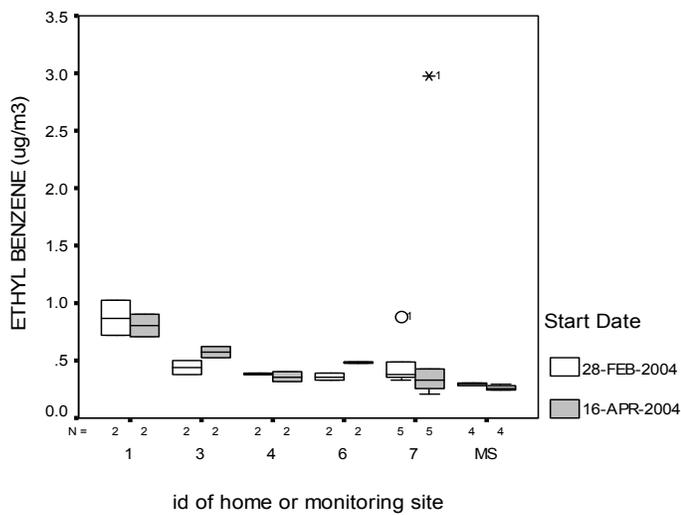
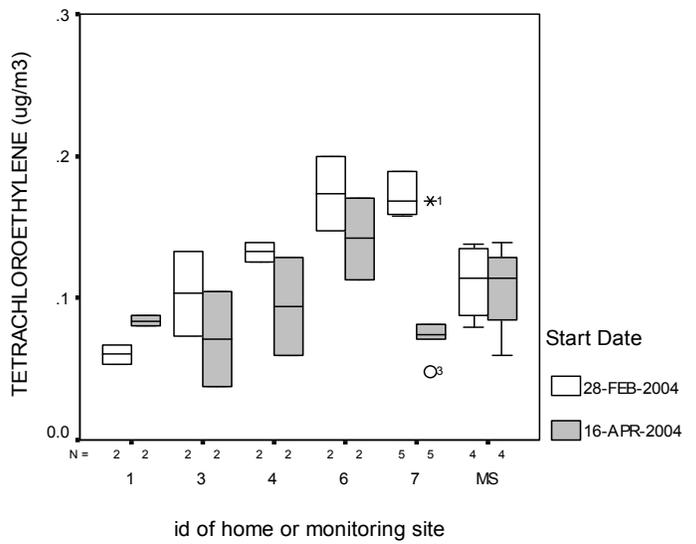
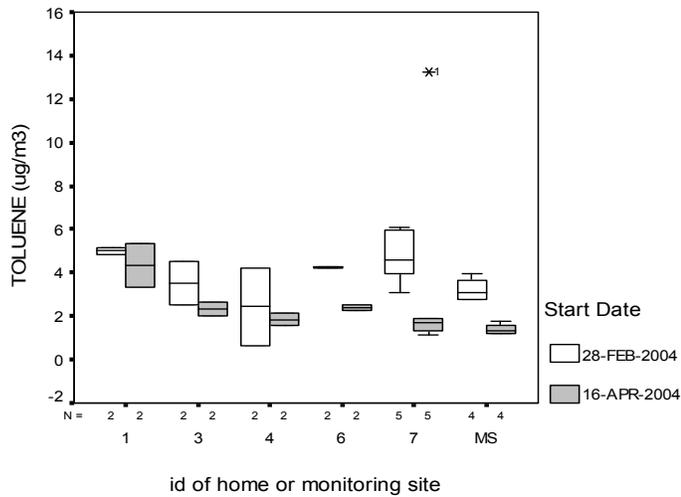
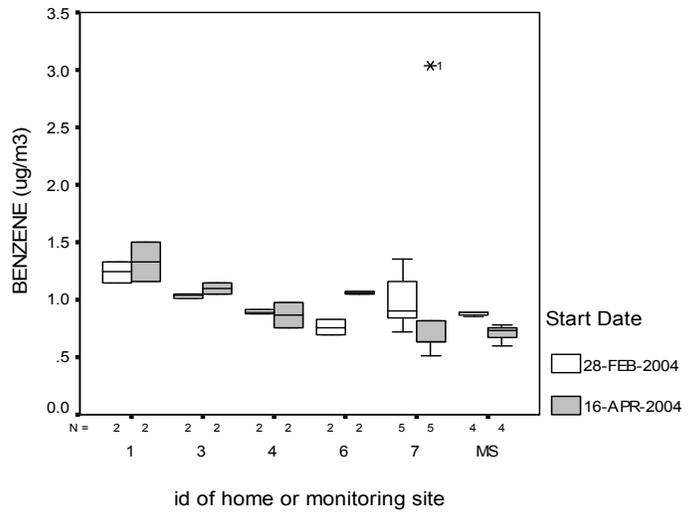
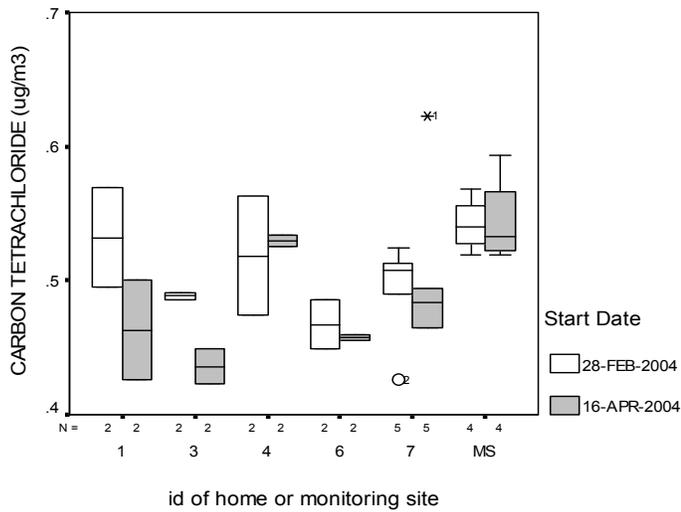
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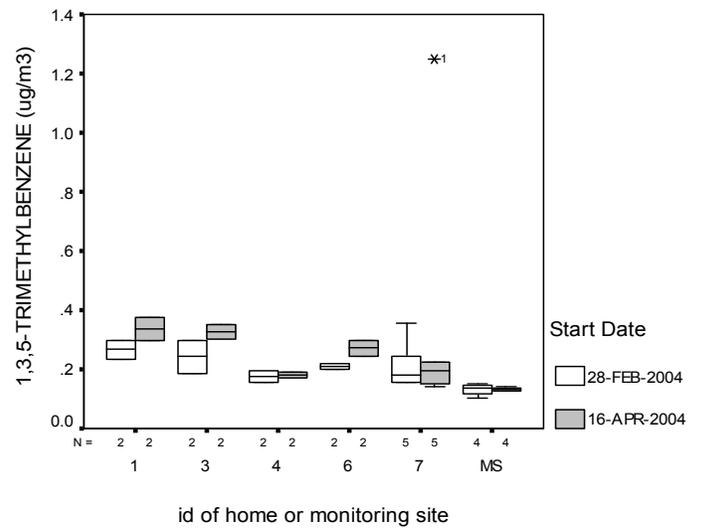
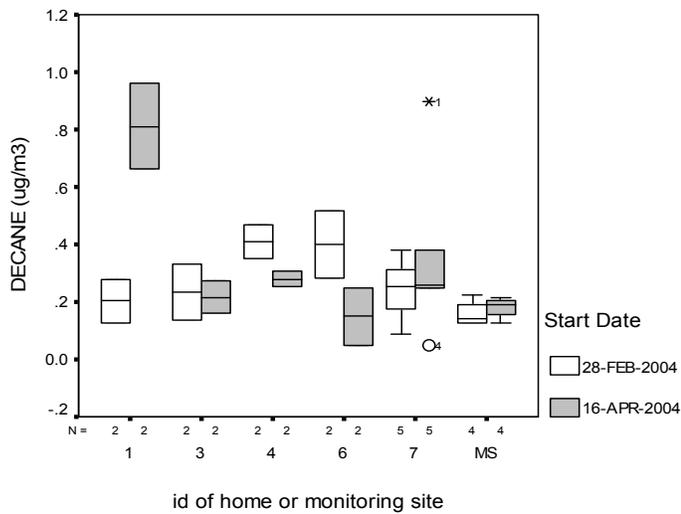
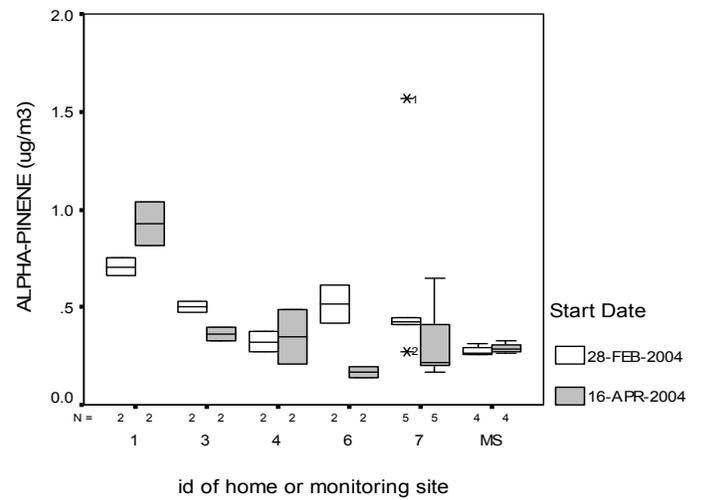
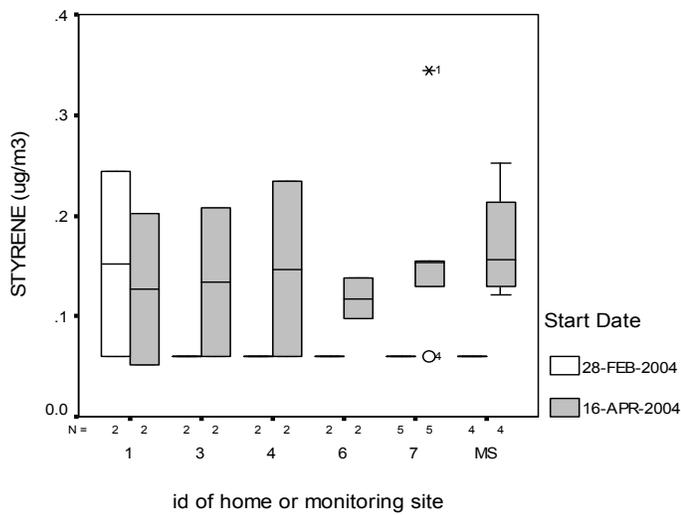
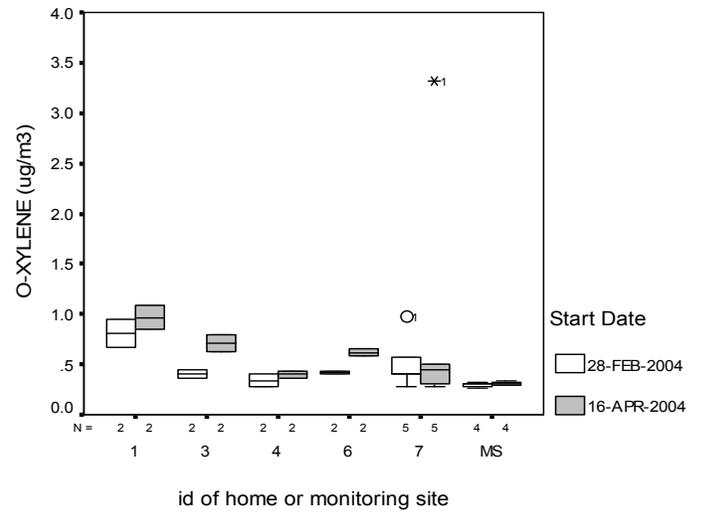
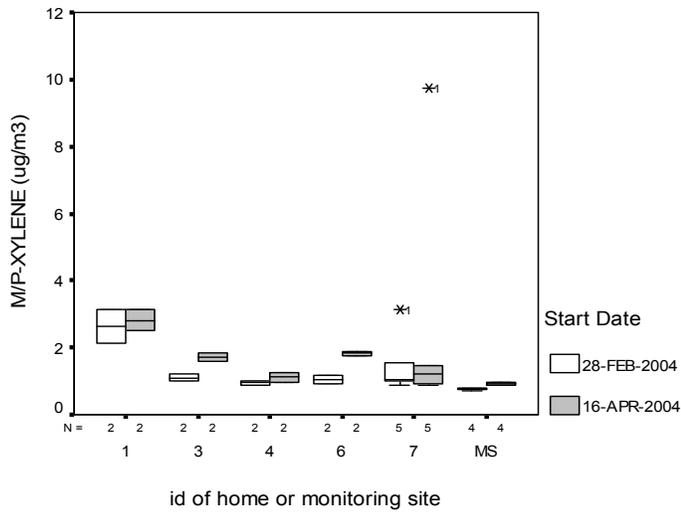
Phase III supplemental Box Plots of VOC Concentrations, by Sampling Period and Site of Measurement

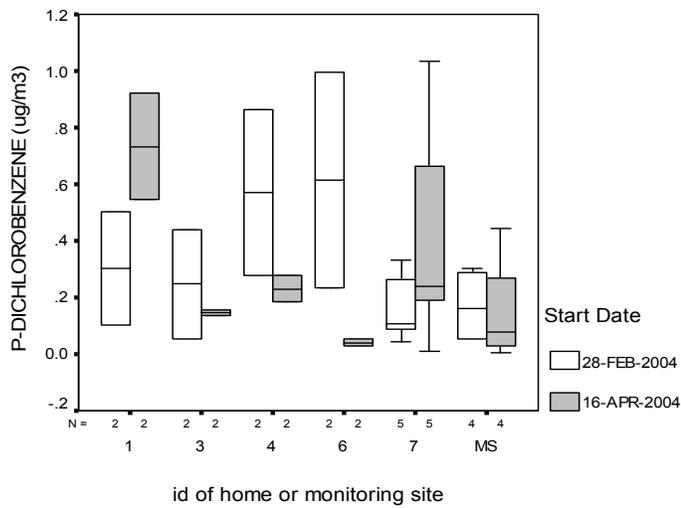
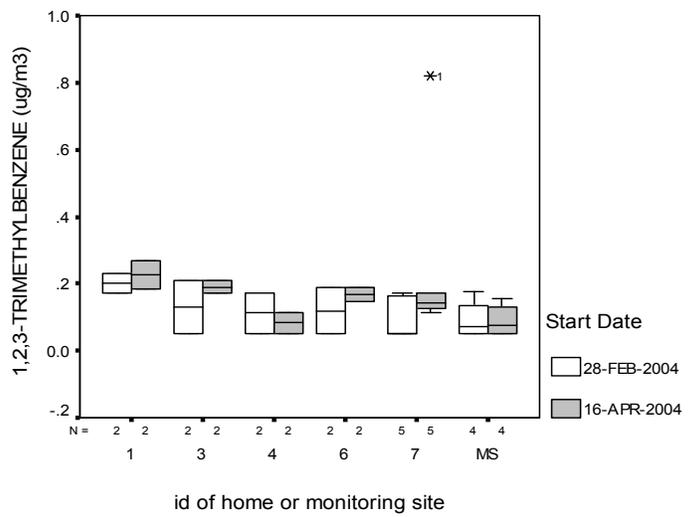
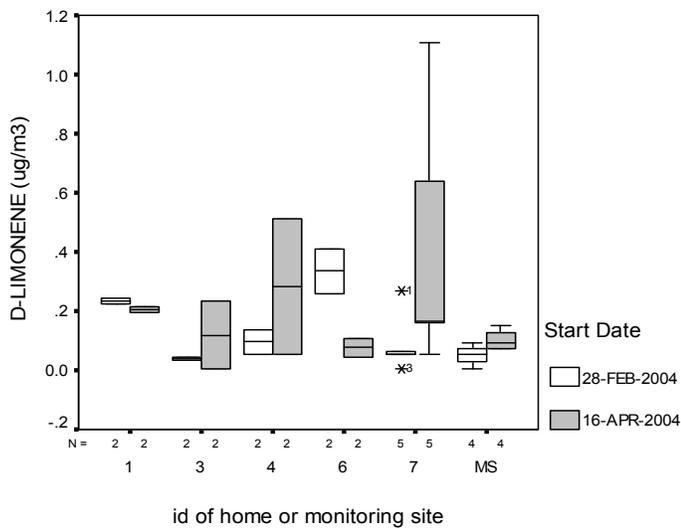
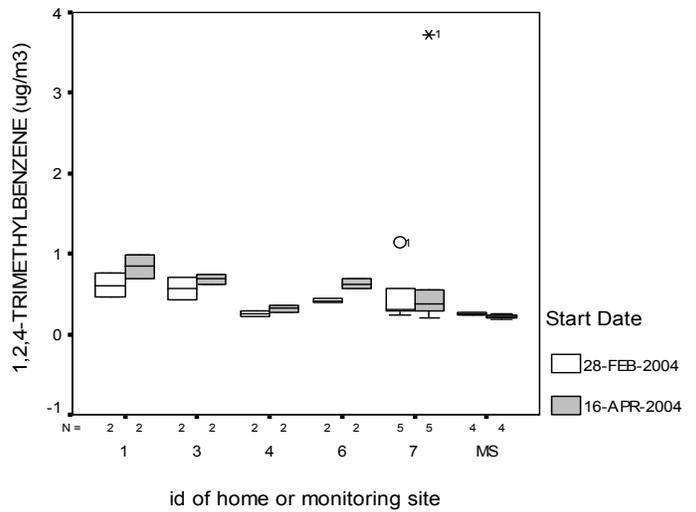
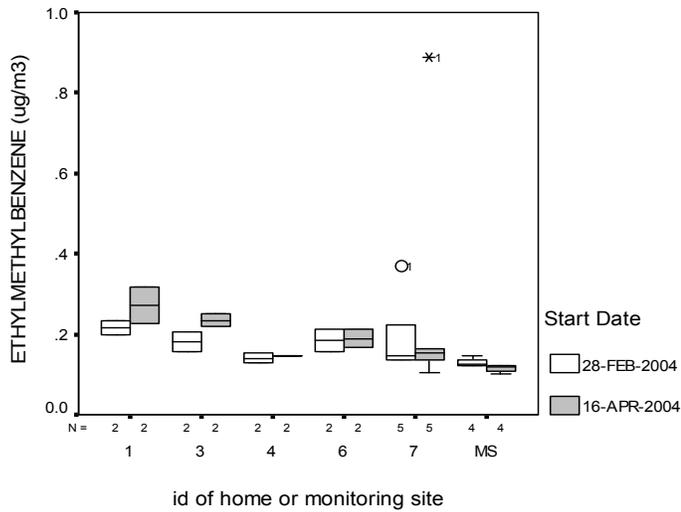
Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with an open circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

Aldine





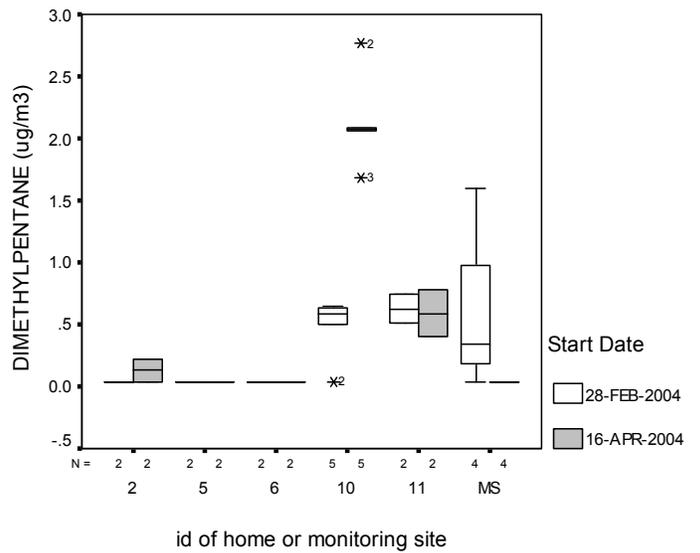
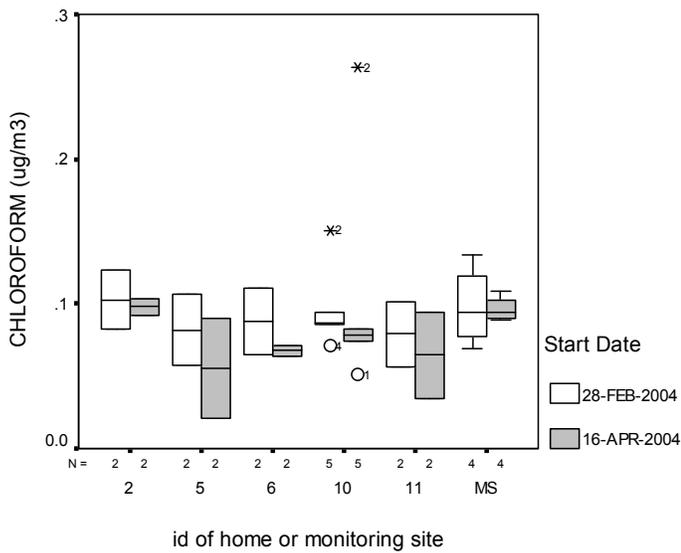
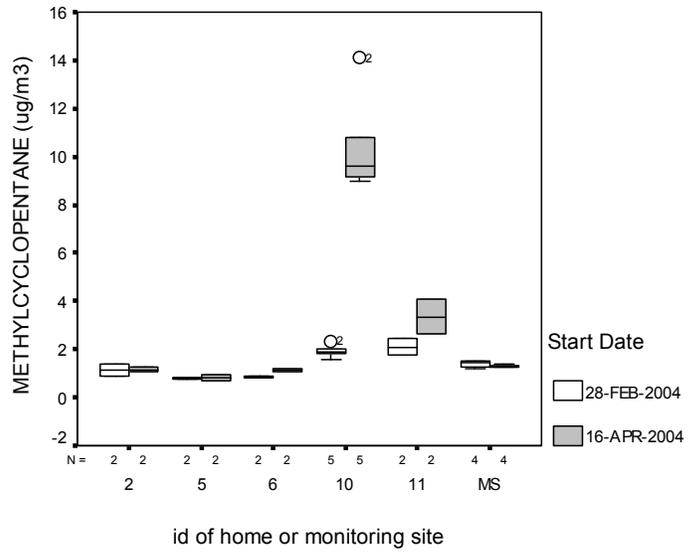
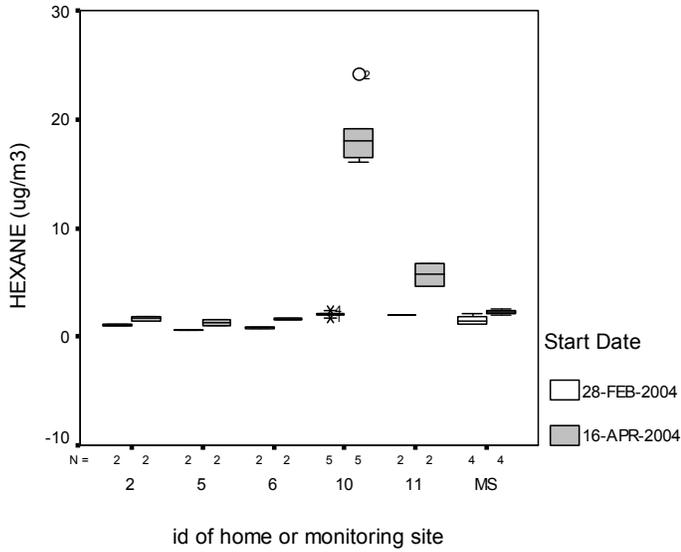
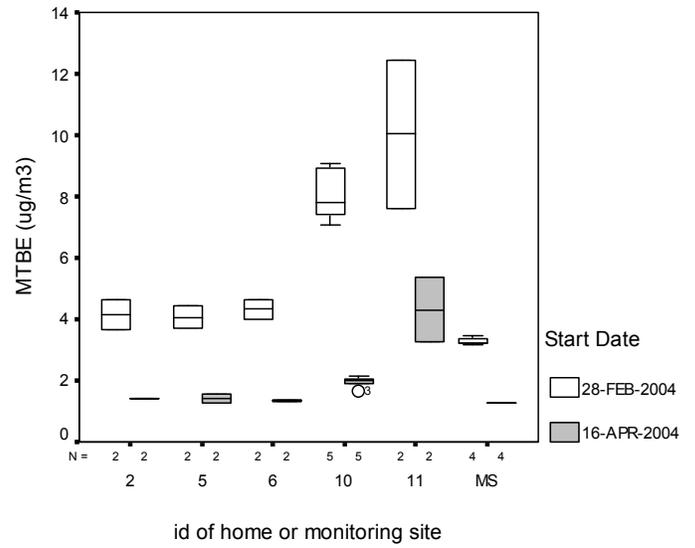
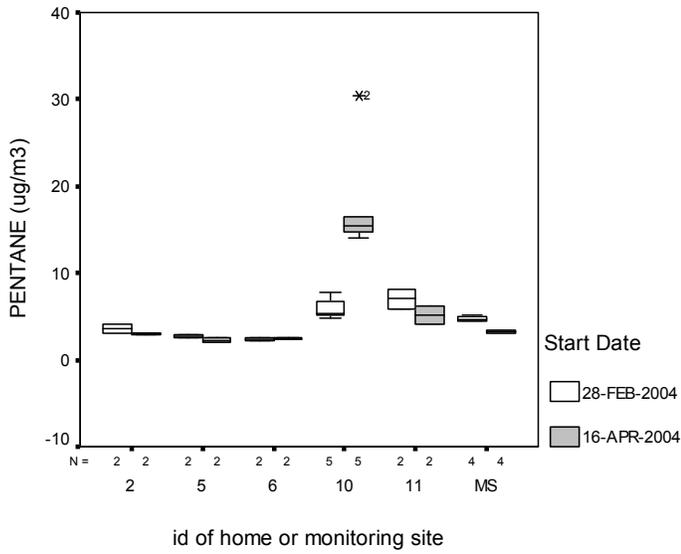


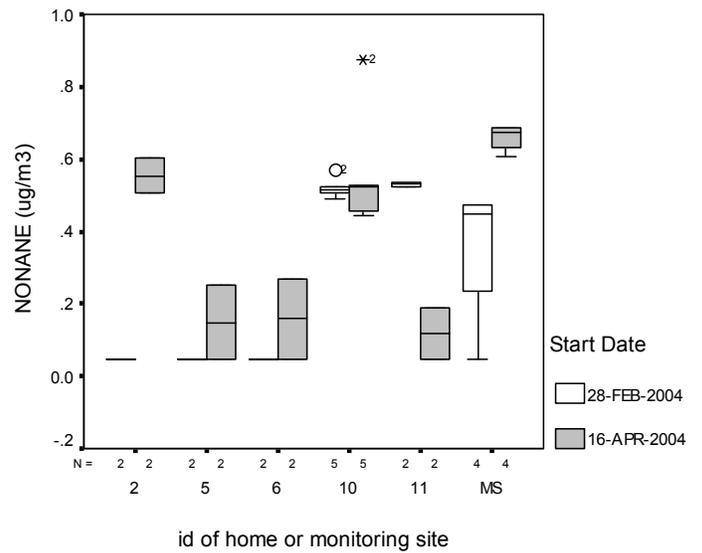
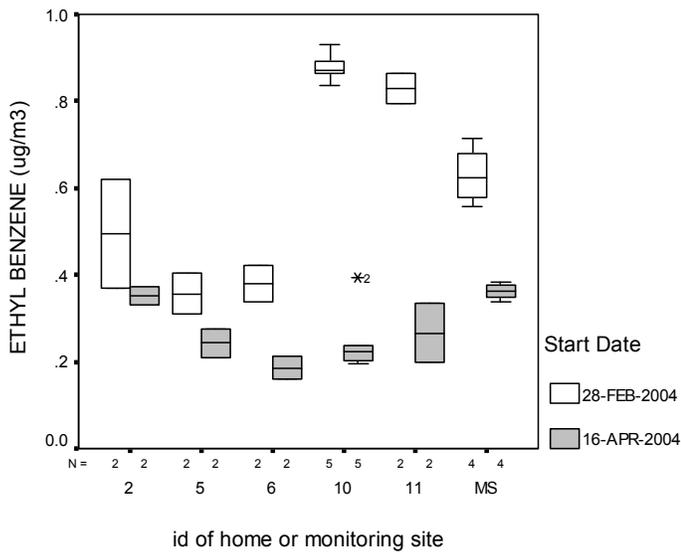
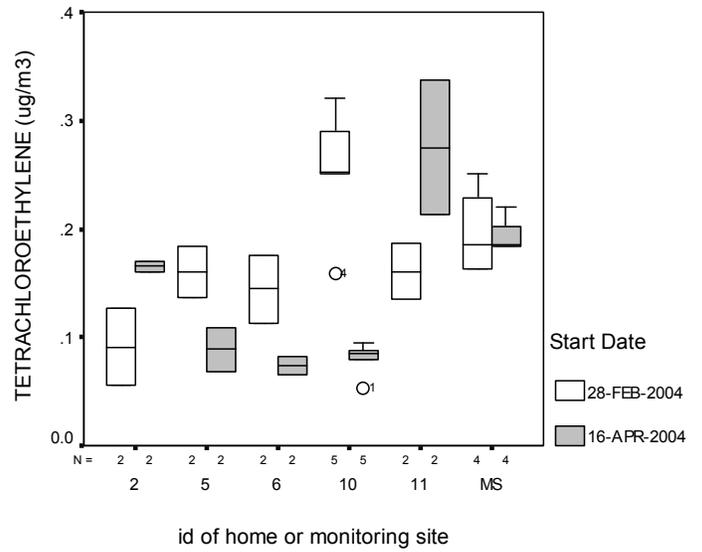
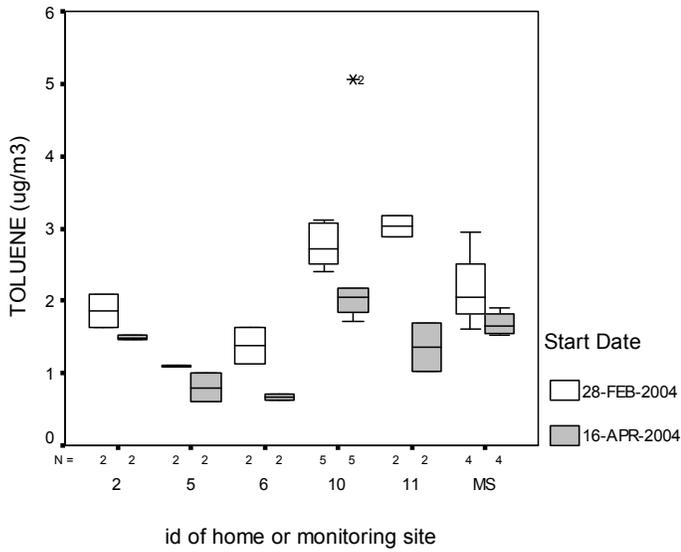
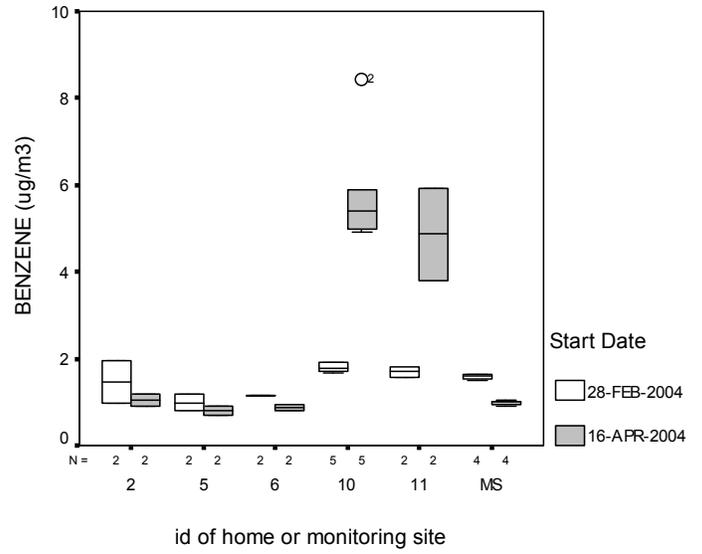
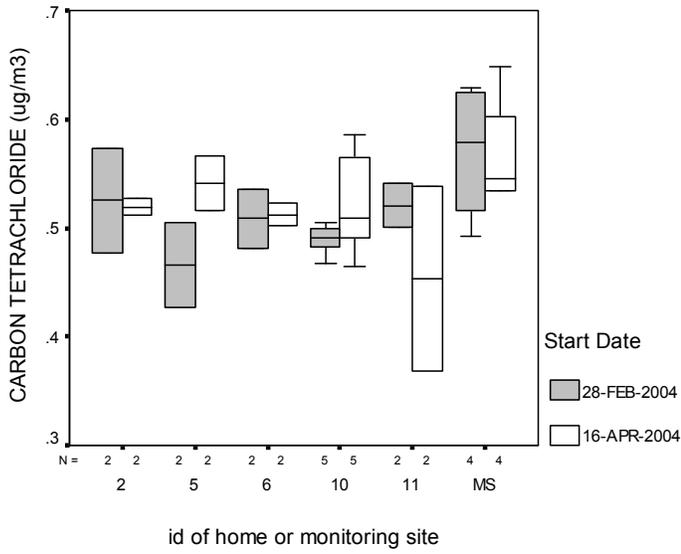


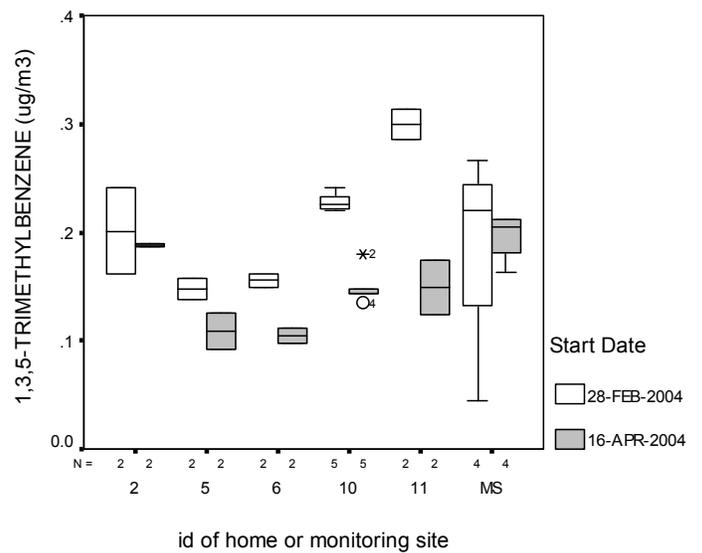
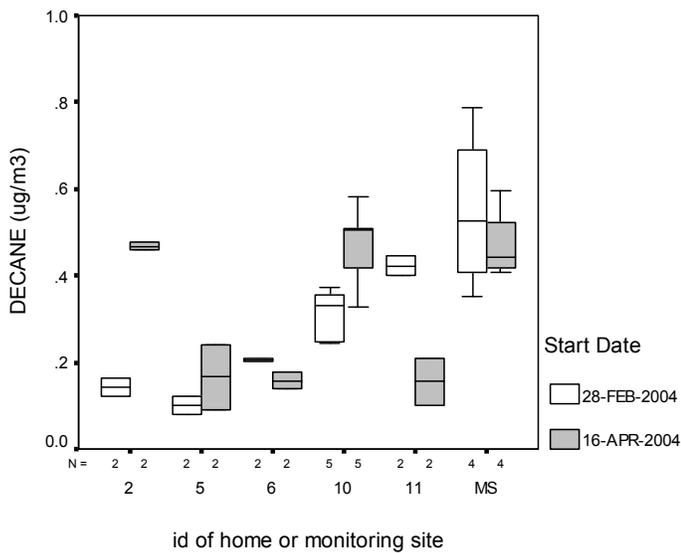
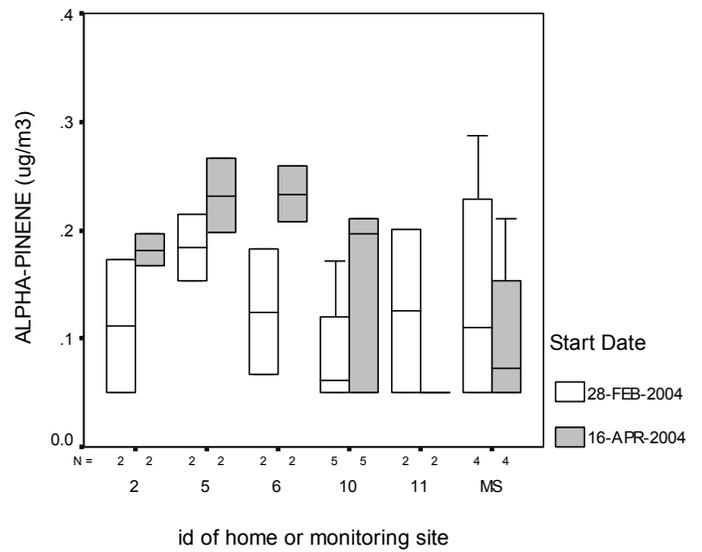
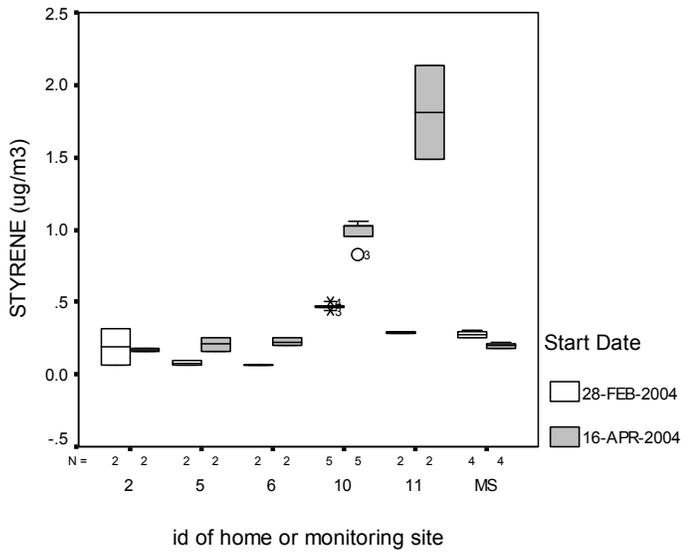
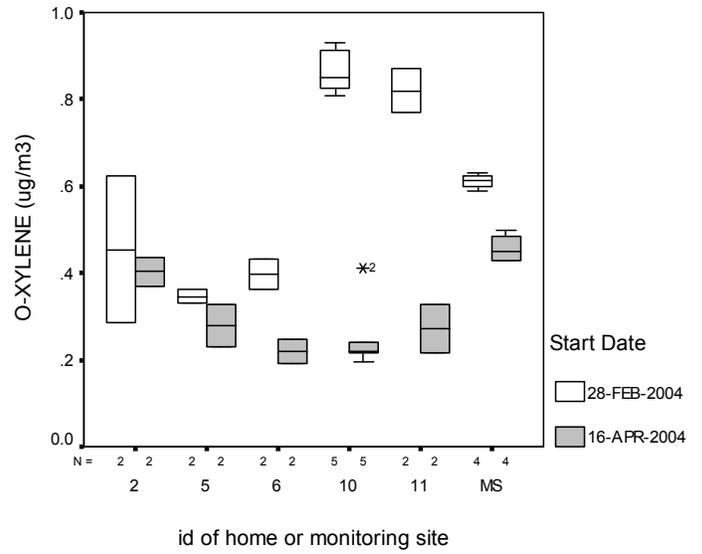
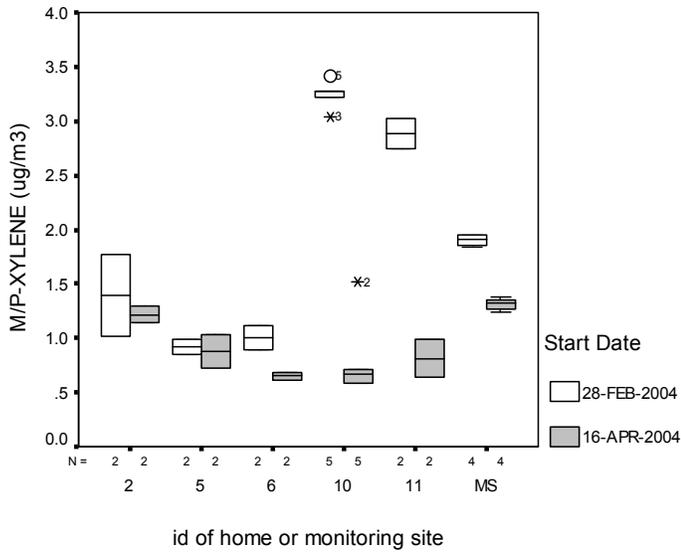
Appendix E

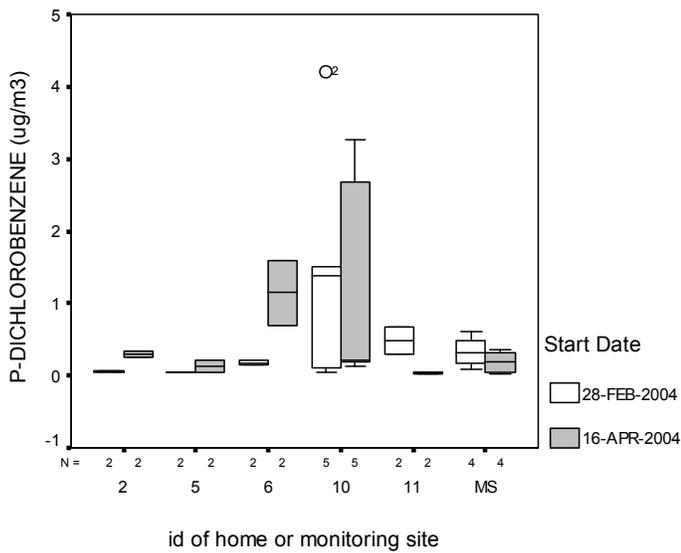
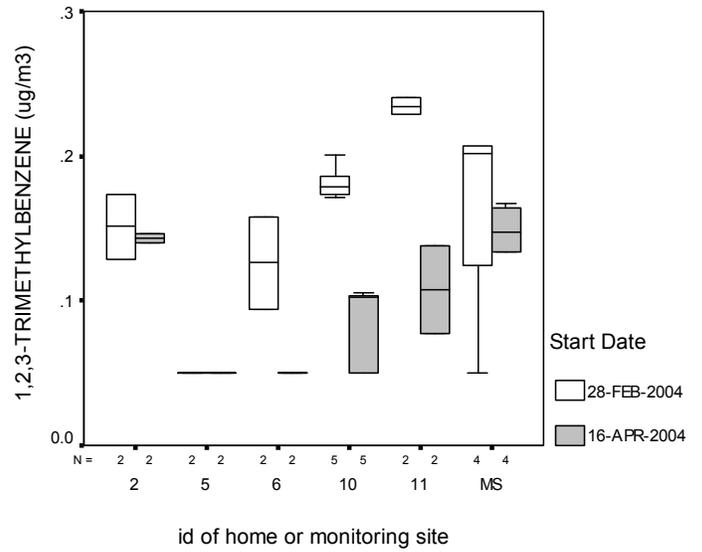
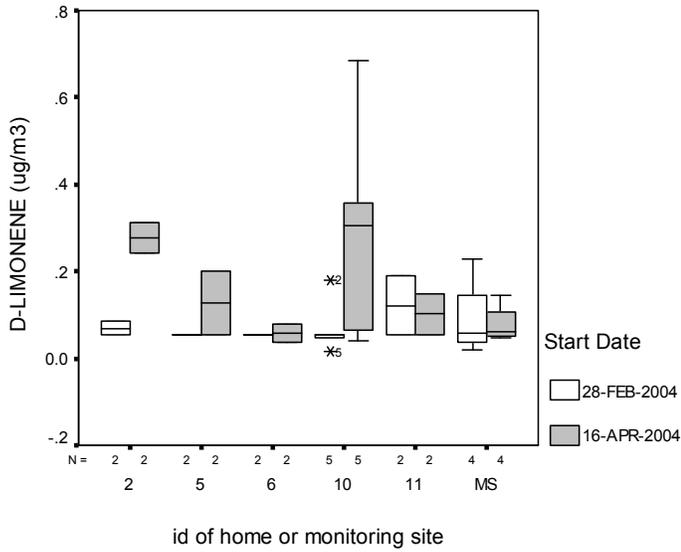
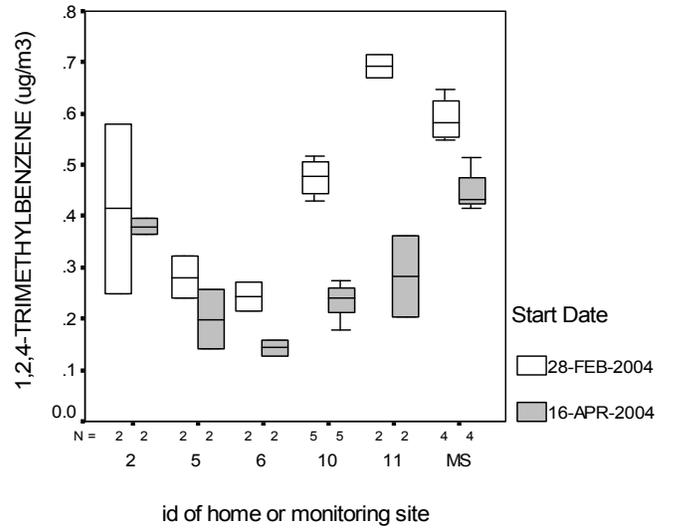
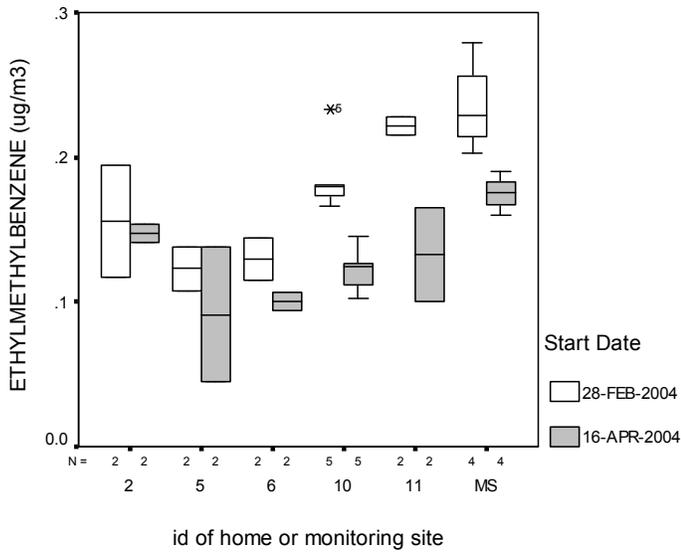
Phase III Supplemental Box Plots of VOC Concentrations, by Sampling Period and Site of Measurement

Clinton





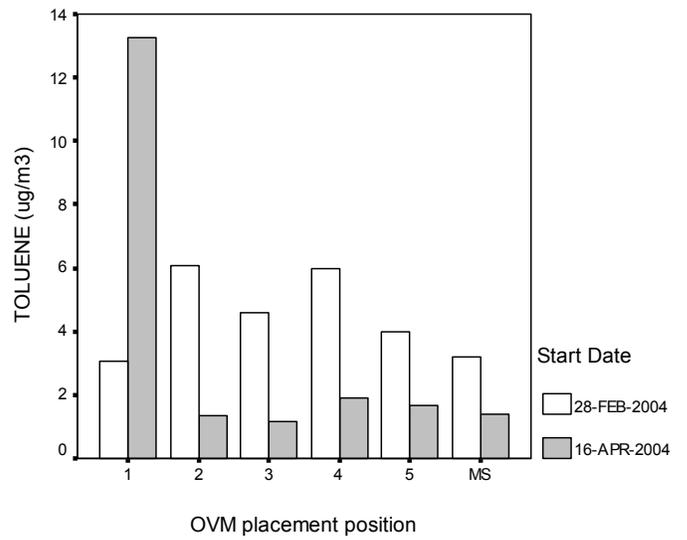
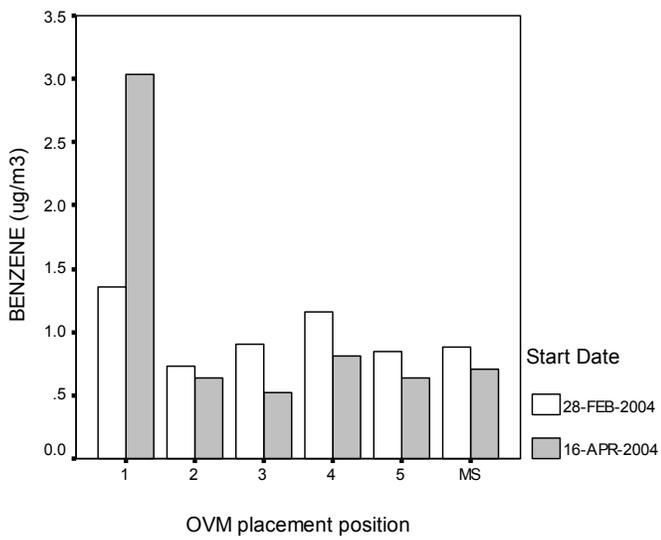
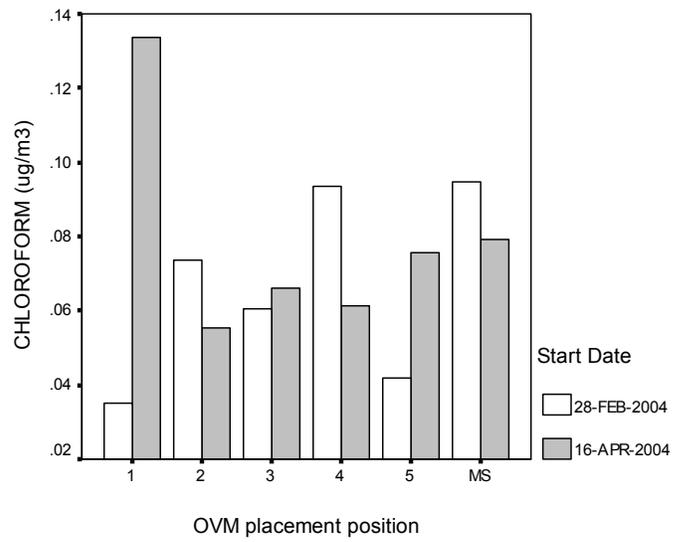
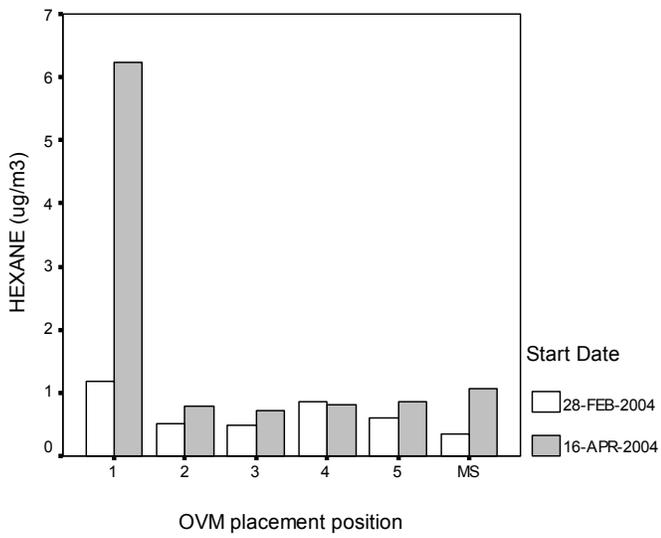
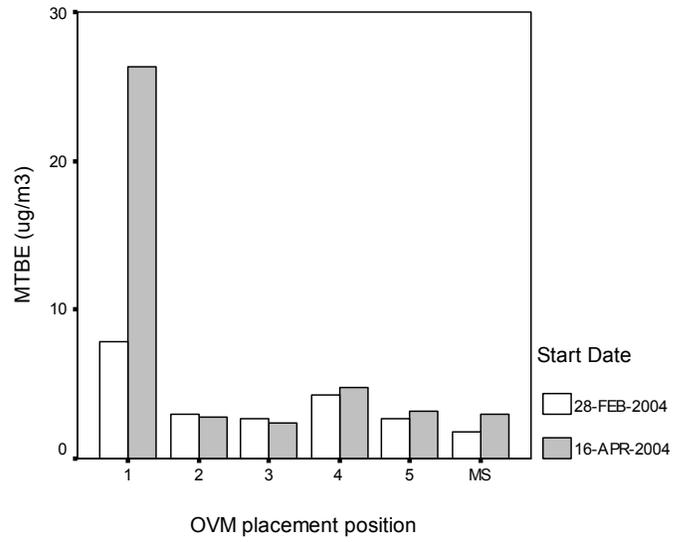
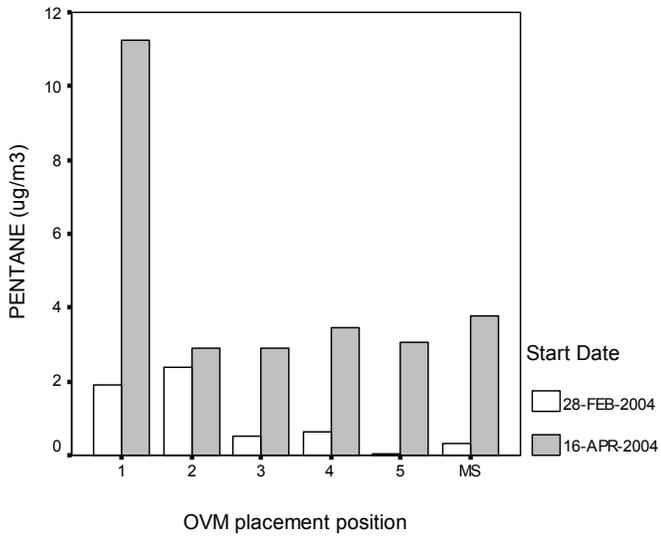


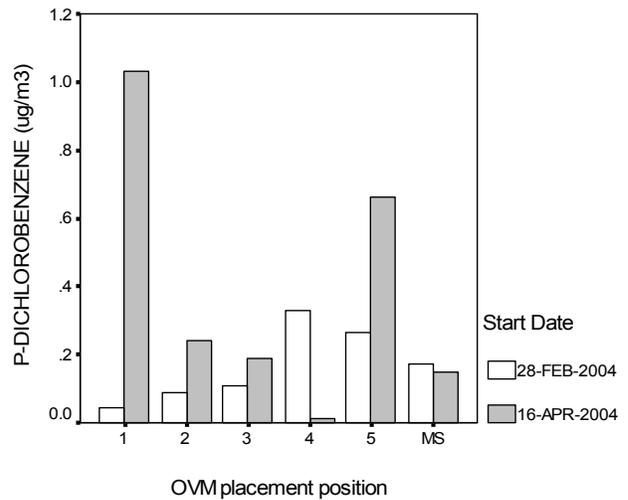
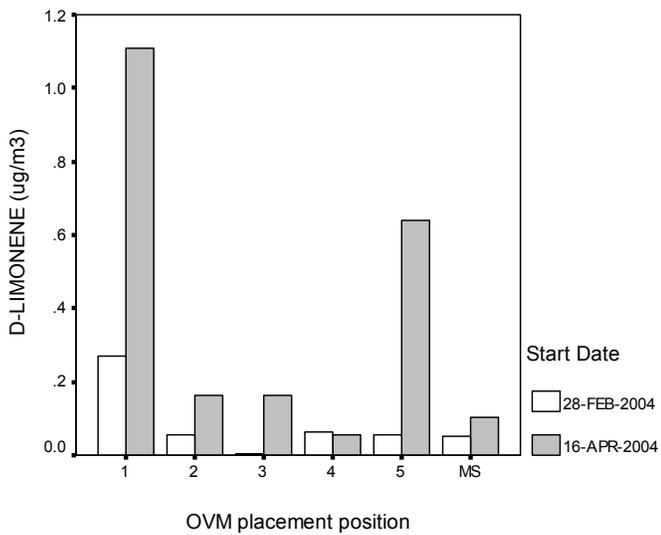
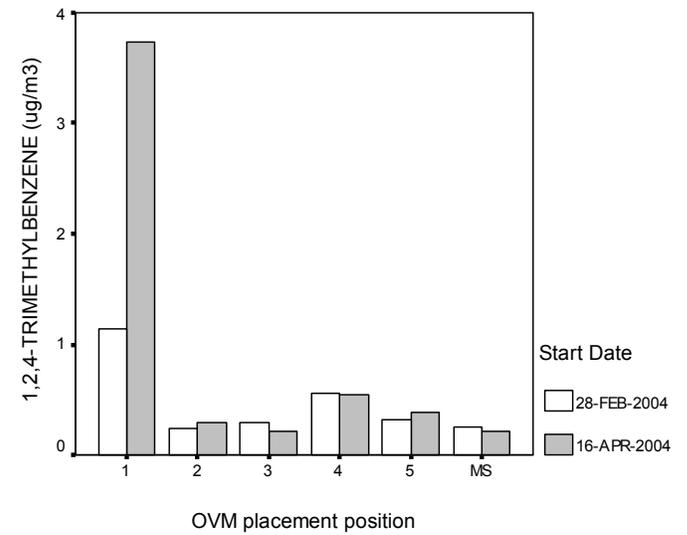
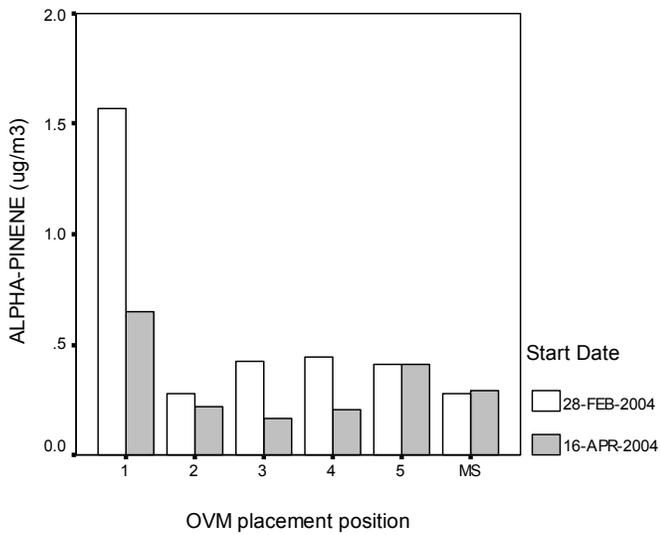
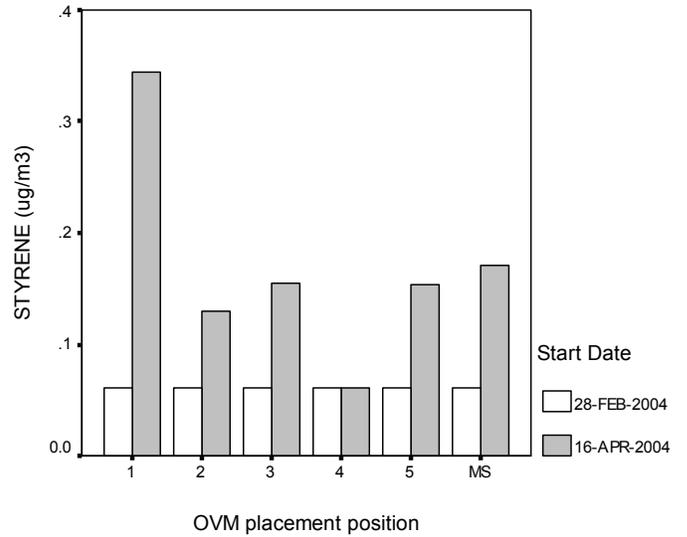
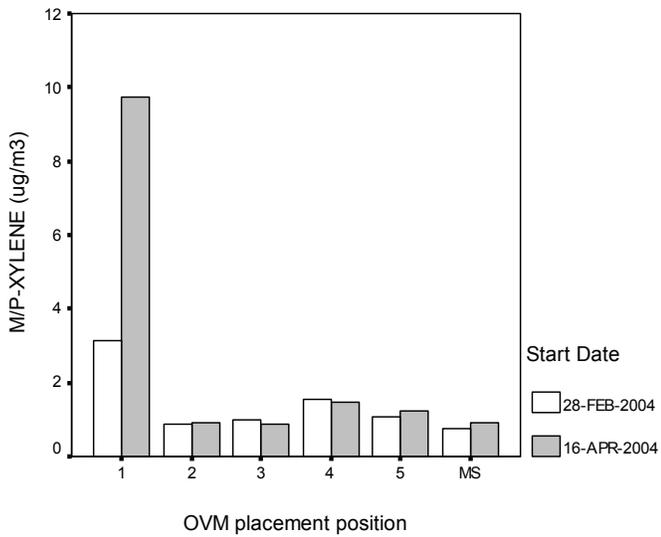


Appendix F

Bar Graphs of VOC Concentrations, by Sampling Period, For Each OVM Sample Position

House A7





**B. Bar Graphs of VOC Concentrations, by Sampling Period,
For Each OVM Sample Position**

House C10

