Traffic Related Exposure Assessment in Dallas, TX, for Ambient Volatile Organic Compounds and NO_2/NO from 24 fire station sites: Summer 2006 and Winter 2008

Prepared by

Luther Smith, Laura Liao, and Casson Stallings
Alion Science and Technology, Inc.

Prepared for

Principal Investigator
Kuenja C. Chung, Ph. D.

Multimedia Planning and Permitting Division
Air Quality Analysis Section
U. S. Environmental Protection Agency, Region 6
Dallas, TX

Under Contract Number EP-D05-065

April 26, 2010

Contents

Part I. Study summary for summer 2006: P3

Part II. Study summary for winter 2008: P48

Part III. Monitoring data summary by site – Mean values: P57

Part IV. Maps for measured and predicted for benzene and NO2: P60

Part I
Passive Monitoring of VOCs and NO_2 in Dallas, Texas
Summer, 2006

Section 1 – Introduction

The goal of this project was to gain a more complete overview of volatile organic carbon (VOCs) and NO_2/NO_x levels in the city of Dallas, Texas. The study area was defined roughly as the interior of the loop formed by Interstate 635 to the north and east, Interstate 635/20 and Interstate 20 to the south, state highway 406 in the southwest, state highway 12 to the west, and Interstate 35 completing the loop in the northwest. In addition, a buffer of approximately two kilometers was added outside this area. See Figure 1.

To accomplish this, passive monitoring devices (PSDs) for the pollutants of interest were deployed at twenty-five sites across the study area. The data obtained were used to develop predictive models based on ancillary variable values which could be determined at any location within the study area. For purposes of comparison between methods, EPA decided that one of the twenty-five sites would be located at the existing Hinton (continuous) air quality sampling installation.

The remaining twenty-four passive monitoring sites were placed at fire stations. The use of fire stations offered several advantages. First and foremost, they are well-distributed across the city from a geographic standpoint. Secondly, only one agency needed to be consulted for permission to conduct the sampling. Fire stations typically would be expected to have enough open physical space to accommodate the samplers, and physical access to the collectors would not generally be difficult. Finally, the potential for vandalism of the samplers would be low since the fire stations would not have enough open space or other features (e. g., playground equipment) to attract people who might be tempted to disturb the samplers and the stations are staffed around the clock.

The sampling was conducted between August 1, 2006 through September 5, 2006. Five week long samples were collected at each site, with duplicate samples collected at two locations. The VOCS were sampled with Carbopack X diffusive sampling tubes, and the NO_x species were collected with Ogawa PSDs. Sampling devices were installed by Alion personnel. Volunteers from the local area collected the samples on a weekly basis. Each week EPA shipped the collected samples to Alion for chemical analysis. Prior to the initiation of sampling, Alion personnel provided training in the collection of samples, their shipment, and the disassembly and return of the sampling equipment; hard copies of the operating procedures were provided to each person collecting samples. Details of all quality assurance related topics including standard operating procedures for both field and laboratory are provided in the Quality Assurance Project Plan (Alion, 2006) developed at the beginning of the project. (This document was provided earlier.)

Section 2 of this report describes the procedure by which sampling locations

were determined. This description was provided to EPA earlier, but is repeated here because it is so closely connected to the results obtained, which are reported in Section 3.

Section 2 - Site Selection Preanalysis for Dallas VOCs and NO_2/NO_x Monitoring

Determination of Ancillary Variables

As mentioned above, predictions at unmonitored locations were to be made on the basis of ancillary variables whose values could be obtained through geographic information systems (GIS) technology at any point within the study area. Based on the results of earlier work conducted in El Paso, Texas (Smith et al., 2006), consideration was given to the following types of ancillary predictor variables: distance to roads carrying certain volumes of vehicles; traffic intensity; population density; distance to point sources. Within these general variable types, specific measures were constructed and are listed in Tables 1a-d. (Certain variables, such as distance to a border crossing and elevation that were used in El Paso were irrelevant for the Dallas study.)

Geographic locations of the fire stations were based on the addresses provided in the Dallas Fire-Rescue web site, and monitoring locations were subsequently verified in the field with a global positioning system. GIS, implemented in ArcView® v3.2 (ESRI, Redlands, CA), was used in conjunction with data obtained from various sources to calculate the different specific measures of the general ancillary variables.

Based on the road network available from GIS and modeled traffic count data for Dallas County supplied by the Texas Department of Transportation, distance to roads was measured in two ways, each having several individual measures. One type of road distance measure was to consider the distance from a location to the nearest road having a traffic volume contained between two specified bounds. For example, variables established in this manner were DIST_5KI (the distance to the nearest road with a traffic volume greater than 0 but less than or equal to 10,000 vehicles per day) and DIST_15KI (the distance to the nearest road with a traffic volume greater than 10,000 but less than or equal to 20,000 vehicles per day). A somewhat similar, but distinct, measure was the distance to the nearest road having a traffic volume of at least a specified amount. For example, such variables included DIST_10KP (the distance to the nearest road with a traffic volume greater than or equal to 10,000 vehicles per day) and DIST_20KP (the distance to the nearest road with a traffic volume greater than or equal to 20,000 vehicles per day). Distance to road variables are listed in Table 1a.

GIS and the traffic count data were also utilized to establish measures of traffic intensity. These variables were defined to be the number of vehicles per day per km of road within a specified radius of the location; these variables are listed in Table 1b. Radii used were 125, 250, 500, 1000, 1500, and 2000 m buffers, and the resulting variables were designated INT125, ... INT2000.

Population measures (variables listed in Table 1c) were established using data from the 2000 U.S. Census. One variable, POP_DEN, was simply the population of the census tract containing the location; UNIT_DEN was similarly defined for housing unit counts. Similar to traffic intensity, population density (people per km^2) and housing unit density (housing units per km^2) values were calculated within radii of

125, 250, 500, and 1000 m buffers; the resulting variables were designated as P_125, ... P_1000 and U_125, ... U_1000, respectively.

Distances to the nearest point source of different sizes for various pollutants were calculated in m. Point source emissions estimates were obtained from EPA's National Emissions Inventory. These ancillary variables are listed in Table 1d.

Selection via Correlation Analysis of Ancillary Variables for use in Prediction

This process generated a total of fifty-one potential predictors. Of course, many of these would be expected to be highly correlated, and one would not want to use them all. The following approach was used to trim this list to a reasonable collection with which to attempt the predictions at the unmonitored locations. First, the variables were grouped by variable type, as they appear in Tables 1a-1d.

The philosophy behind selecting variables from within these groups was that one would only want to include variables that were weakly correlated within a group, since adding a highly correlated variable to one already selected would not contribute much to the predictive capability. To be useful for predictive purposes, the selected variables also needed to exhibit a reasonable amount of variability across the study area. Additionally, there was a predisposition to select variables incorporating short radii or close distances on the assumption that conditions nearest the site would have the most influence on the pollutants considered here.

For each of Tables 1a-1d, Pearson correlations (r) of the variables within them were calculated. These correlation tables and data plots were then examined utilizing the criteria outlined above. The variables selected as potential predictors are indicated in Tables 1a-1d.

Thus, of the total of fifty-one ancillary variables created, eleven were retained for consideration in developing the predictive equations: population density, traffic intensity within one kilometer of the site, five road distance variables, distance to two size categories of NO_x emitters, and distance to one size category each of benzene and ethylbenzene point sources.

Selection of monitoring locations

The fifty-five fire stations active at the time of the study were initially considered for monitoring. However, two (stations #10 and #13) were immediately eliminated because they are located in Denton County; these stations were the farthest removed from the defined study area, and traffic data from Denton County were not obtained.

The remaining fifty-three fire stations and the Hinton monitor were then ranked on each of the individual variables and divided into six groups of nine based on these rankings. The groups were designated from 1 (nine lowest ranked sites) to 6 (nine highest ranked sites).

To ensure a reasonable distribution of monitoring locations across the city, the study area was divided into five sections: central Dallas (thirteen sites); northeastern (ten sites); southeastern (seven sites), southwestern (eight sites), and northwestern (twelve sites). See Figure 2. (Note that in Figure 2 stations #10 and #13 are separately indicated. Also, stations #7, #56, #9, and #12 are all outside the defined study area and

are separated from the other sites as well.)

The rankings with respect to the ancillary variables provided the basis for the selection of monitoring sites. Five sites were selected in each section, with the exception of the southeastern section where only four sites were chosen. Within each section, sites were chosen so that, to the extent possible, the rankings both within and across all ancillary variables included high, medium, and low values. (Though outside the study area, stations #7, #9, #12, and #56 were included in the rankings in case they were needed to fill "gaps" in the ranges of the ancillary variables; as it happened, none of these sites were needed.)

After this initial selection, the chosen and nonselected fire stations were examined from several different aspects. First, it was verified that the selected and nonselected sites spanned similar ranges for each of the individual potential predictor variables. Generally, the selected sites covered a slightly larger range. Beyond simply looking at the range of values for the individual variables, the groups formed by the rankings were examined as well. For each individual predictor, it was verified that each of the six groups contained some chosen sites.

In developing predictive equations from the monitoring data, it is important not only that the individual variables be adequately represented but that the mathematical space spanned by the collection of potential predictors also be well-covered by the chosen sites. This was checked in two ways. First, Pearson correlations were calculated between each of the eleven potential predictors; calculations were done separately for the selected and nonselected sites. Generally, the correlations between variables were weak for both the monitored and unmonitored groups of sites. More importantly, pairs of variables had similar correlations between the two groups. Table 2 reports the correlation for both the chosen and nonselected sets of fire stations.

Cluster analysis was the second multivariate approach used to establish the suitability of the selected sites for developing predictive equations that could be extended to the entire study area. All the sites inside the study area were clustered based on all eleven ancillary variables. Six clusters were formed, and each cluster contained sites that had been selected. (A similar clustering procedure was done with all sites except the two in Denton County. In this process, the stations outside the study area fell into three separate clusters of their own – one for stations #7 and #56, and one single-site cluster each for stations #9 and #12. This confirms the decision not to choose any of these four sites for monitoring.)

The final aspect of site selection was to physically visit each site and evaluate its suitability for serving as a monitoring location. All sites except two were found acceptable. One site was located near automotive repair businesses, including a paint shop, and the other was problematic due to the proximity of a parking lot and some trees. The preanalysis results described above were utilized to suggest alternative fire stations.

Section 3 – Results

The monitoring generally went quite smoothly. Including duplicates, 135 weekly samples were possible over the five week period; 133 valid samples were

obtained. Generally, levels were quite low. Table 3 provides the method detection limits and the below detection limit (BDL) counts for each the twenty-five monitored VOCs; the nonzero BDL counts indicate values that were below the method detection limit but above the analytical detection limit. One observes that for seven of the VOCs no sample was ever measured as above the detection limit. These were: Freon 114; 1,1-dichloroethane; *cis*-1,2-dichloroethene; 1,2-dichloropropane; trichloroethene; chlorobenzene; *m*-dichlorobenzene. Note that for several of these, all values were below even the analytical detection limit. In addition, styrene was below the detection limit in 41% of the samples collected.

Neither NO_2 nor NO were ever below detection; however, both exhibited low concentrations in the weekly samples. NO never exceeded 20 ppb, and in fact, only four samples found NO levels at or above 10 ppb. (These levels were 10, 10, 11, and 19.)

Table 4 reports the precision from the two duplicate monitoring sites for all species measured. The table presents precision in the form of the mean absolute difference both in terms of concentration units and as a percentage. Precision was generally quite good as evidenced by the very low absolute differences. Note that while a few of the percentage differences are quite high, this was driven by the fact that the actual concentrations were very low.

Table 5 provides the mean and median values and Table 6 provides the minimum, maximum, and several percentiles (over all sites and weeks) for those chemicals for which regression equations were determined. No regressions were attempted for styrene or any of the seven compounds that were always below detection. In addition, regressions for Freon 11 and 1,1-dichloroethene were not attempted because they occurred at low levels and exhibited only minimal variability across the study area. In Tables 5 and 6, all VOCs are reported in units of ppt (parts per trillion) and NO_2 is in ppb.

As noted above, predictive equations were determined for chemicals for which measured levels were above the detection limit at least 15% of the time (over all sites and weeks) and which exhibited at least some amount of variability across the area. Only the fire station sites were used in developing the equations. The Hinton site was "held out" to check the performance of the equations.

To determine these equations, the observed mean values of the chemicals at each site were plotted against the various potential predictor variables. For each chemical, only those predictors for which the chemical appeared to have reasonably consistent behavior were retained for use in developing the equations. The statistical approach used to determine the predictive equations was multivariate linear regression. In some instances, this was applied with the chemical measurements log-transformed, and in some cases, predictor variables were log-transformed. (See Table 7.)

When the regressions were first attempted, residual analysis showed that for each chemical there were a few sites (different for different chemicals) which gave large differences between the observed and predicted values. To mitigate this, the regressions were re-run with each site being weighted by the inverse value of Cook's D statistic calculated from the unweighted regression. Thus, the final predictive equations

downweighted the influence of those sites which departed from the pattern established by the other locations. See Rawlings (1988) for a discussion of multivariate regression including influence diagnostics and weighted regression.

Table 7 displays the final predictive equations with those predictors which were significant at the 5% level shown in bold. (In each case, the equations show all predictors used, not just those reported as significant.) The R^2 values in the table indicate how much variability in the chemical is explained by the predictive equation. All R^2 values are reported based on the original (not the log-transformed) scale. At least as indicated by the R^2 values, the success of the predictive equations ranged from very good (carbon tetrachloride and 1,1,1-trichloroethane) to very poor (1,3,5-trimethylbenzene and *p*-dichlorobenzene).

A comparison of the maxima and 95th percentiles in Table 6 indicates that observed values very much higher than the bulk of the other data were recorded for several of the chemicals (*e. g.*, toluene). These outlying values were far enough removed from the other observations that they distorted the mean values for these chemicals. This may in part explain some of the poor R^2 values reported in Table 7.

Of the BTEX species (benzene, toluene, ethylbenzene, and the xylenes), the predictive equations performed reasonably well for benzene, *m,p*-xylene, and ethylbenzene. But for toluene and *o*-xylene neither R^2 was above 50%. The results for the other traffic-related variables, NO_2 and 1,3-butadiene were particularly disappointing with an R^2 of only 34% and 26%, respectively. Based on the significance level of 5% as indicated by the predictor variables appearing in bold in Table 7, the most important single predictor was distance to a large benzene source (BEN1); somewhat surprisingly, however, this variable was not even included in the predictive equations for benzene and toluene based on the scatterplots. The intercept term was significant for all chemicals except *m,p*-xylene, indicating perhaps that other explanatory factors not considered here are contributing to the ambient concentrations. The importance of the other predictive variables differed for the traffic-related pollutants, though not surprisingly, most were connected to vehicle volume. Traffic intensity (INT1000) was found to be significant for benzene and NO_2. Of the distance to roadway variables, the roads of moderate to heavy traffic appeared to have the best predictive power: DIST_75KI for benzene and NO_2; DIST_110KI for ethylbenzene and *o*-xylene; DIST_45KI also helped predict NO_2.

Of the pollutants not obviously related to traffic, there was no specific predictor (other than the intercept) that was especially helpful across pollutants. This is not surprising since most of these remaining chemicals are chlorinated compounds, and none of the predictors considered would be expected, *a priori*, to be associated with chlorine.

Table 8 displays the results of comparing the measured values observed at the Hinton site to the values predicted there by the regression equations. At first glance, the results displayed in Table 8 are disappointing, at least on a percentage basis. This is in part due to the low observed levels. For example, the observed vale of NO_2 was only 12 ppb and the prediction was 15 ppb; however, the percentage difference was 24%. In addition, there may be local conditions at the Hinton site such that behavior of some pollutants with respect to the predictor variables is different than that seen across the

study area. Appendix A provides similar predicted versus observed comparisons for each of the individual monitoring sites.

Figures displaying the predicted values for the various pollutants across the entire study area are contained in a separate file accompanying this report. Yet another accompanying file contains similar figures displaying the mean measured concentrations observed during the monitoring. The maps of the predicted and observed values are similar, as one would expect since the predictions were based on the observed values.

One may observe from these files that, with the exception of toluene, the traffic-related variables (BTEX, NO_2, and 1,3-butadiene) tend to be higher in the central and, possibly, western areas of the city than elsewhere; toluene had higher levels in the north. Tetrachloroethene and *p*-dichlorobenzene were relatively higher in the northern part of the city, while 1,3,5-trimethylbenzene appeared to be higher in the western part of Dallas. The remaining chemicals had relatively elevated levels in the southern or southwestern parts of the study area, except for 4-ethyltoluene which displayed no apparent pattern.

Section 4 – Summary

Twenty-four fire stations were selected for use in passive monitoring of VOCs and NO_2/NO in Dallas. The data collected from these sites were employed to develop spatially predictive models for NO_2 and certain VOCs. Because the sites were chosen in such a way that the predictor variables were well-represented with respect to each individual variable and collectively as well, the models constructed from the sampling data were applicable to the entire

References

Alion Science and Technology, 2006, Quality Assurance Project Plan: Region 6 Multi-task Passive Air Toxics Monitoring and Analysis, prepared for Multimedia Planning and Permitting Division, Region 6, U. S. Environmental Protection Agency.

Rawlings, J. O., *Applied Regression Analysis: A Research Tool*, Wadsworth and Brooks/Cole, Pacific Grove, CA, 553 pp.

Smith, L., S. Mukerjee, M. Gonzales, C. Stallings, L. Neas, G. Norris, and H. Özkaynak, 2006, Use of GIS and ancillary variables to predict volatile organic compound and nitrogen dioxide levels at unmonitored locations, *Atmos. Environ.* 40:3773-3787.

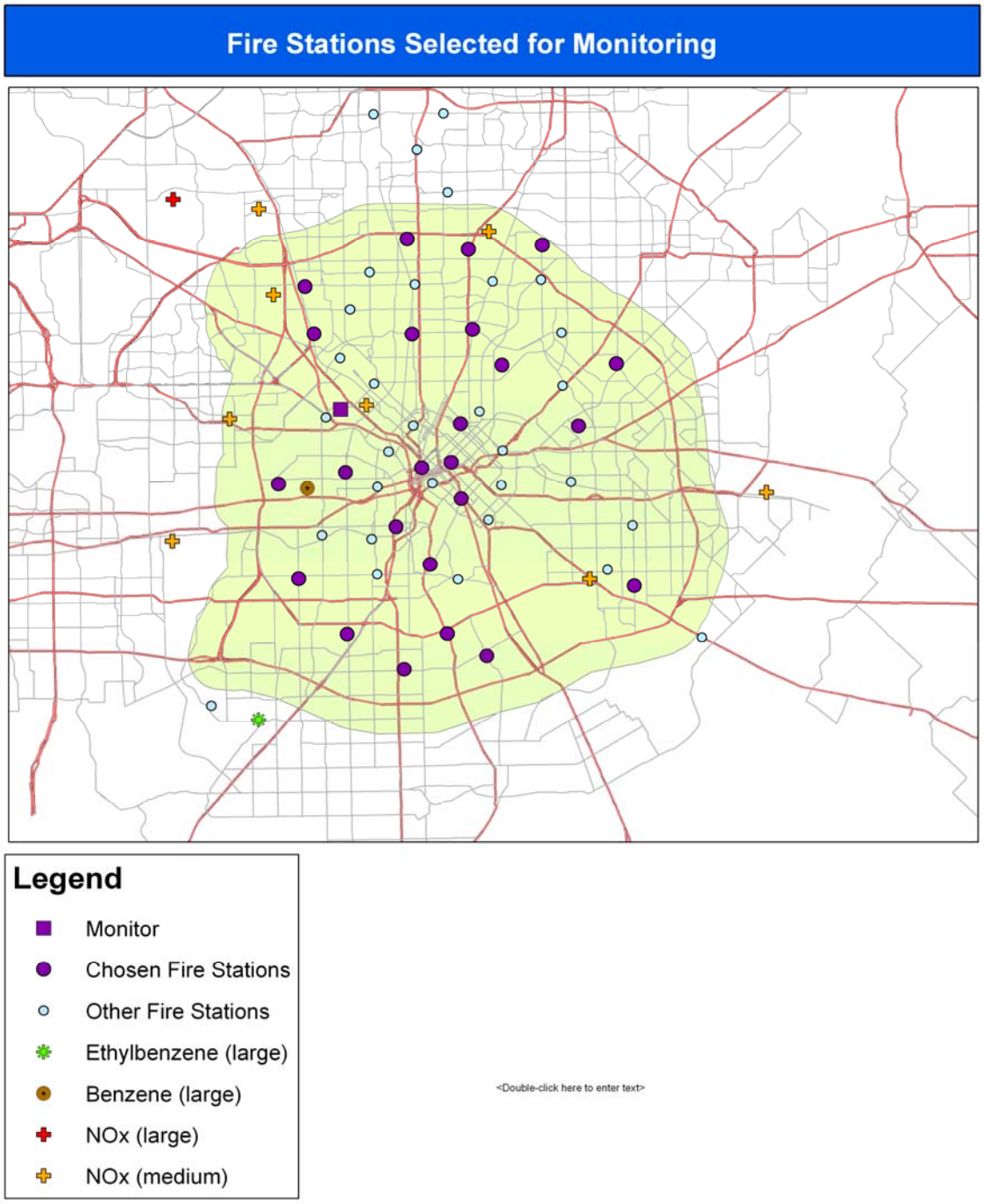


Figure 1. Dallas study area.

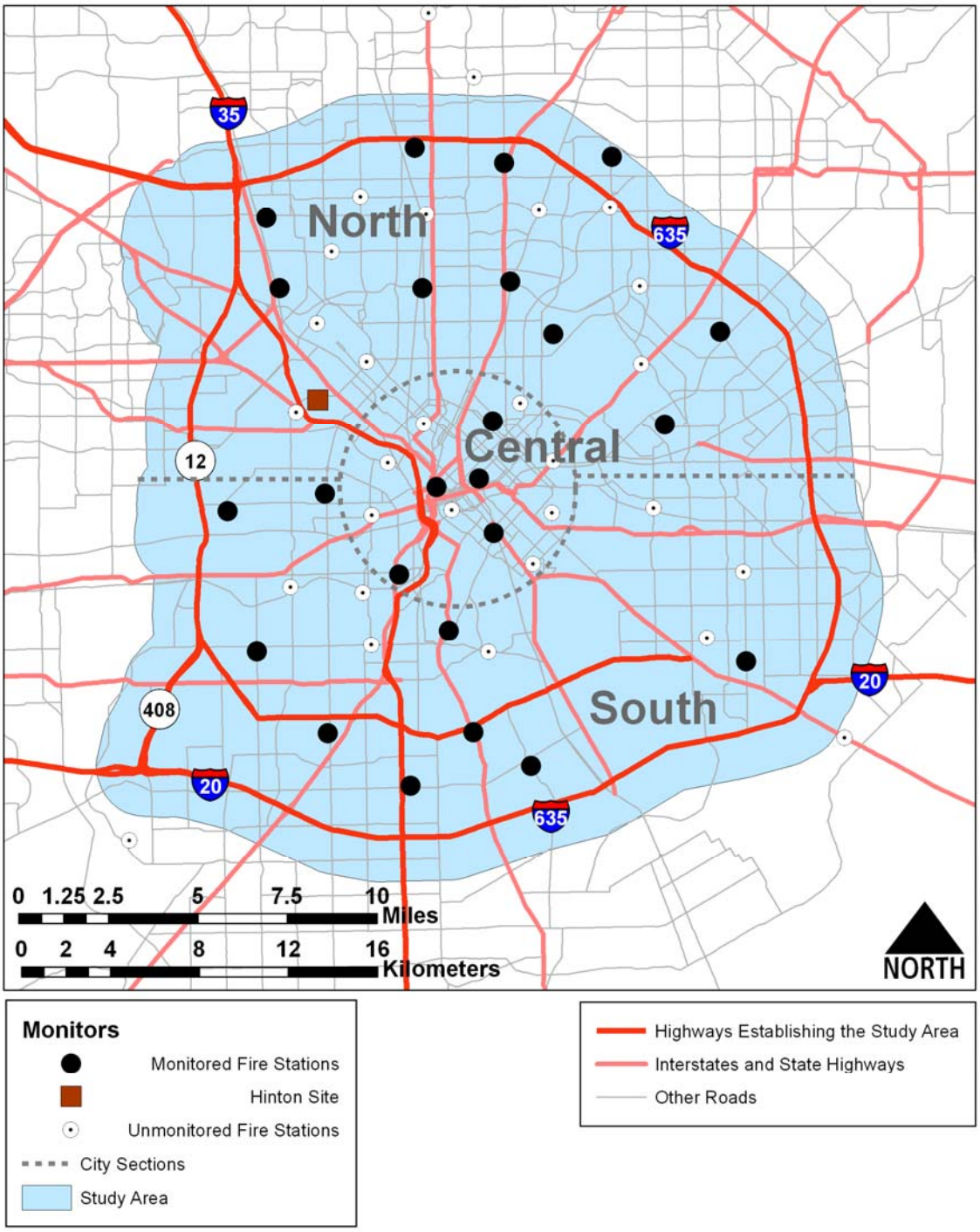


Figure 2. Division of study area into sections. Note that boxes indicate fire stations that are outside the defined study area.

Table 1a. Ancillary variables considered for use in prediction - distance to road.

Variable name*	Definition
DIST_10KP	Distance to nearest road with traffic volume ≥ 10,0000 vehicles per day
DIST_20KP	Distance to nearest road with traffic volume ≥ 20,0000 vehicles per day
DIST_30KP	Distance to nearest road with traffic volume ≥ 30,0000 vehicles per day
DIST_40KP	Distance to nearest road with traffic volume ≥ 40,000 vehicles per day
DIST_50KP	Distance to nearest road with traffic volume ≥ 50,0000 vehicles per day
DIST_60KP	Distance to nearest road with traffic volume ≥ 60,0000 vehicles per day
DIST_70KP	Distance to nearest road with traffic volume ≥ 70,0000 vehicles per day
DIST_80KP	Distance to nearest road with traffic volume ≥ 80,000 vehicles per day
DIST_90KP	Distance to nearest road with traffic volume ≥ 90,000 vehicles per day
DIST_100KP	Distance to nearest road with traffic volume ≥ 100,000 vehicles per day
DIST_120KP	Distance to nearest road with traffic volume ≥ 120,000 vehicles per day
DIST_140KP**	Distance to nearest road with traffic volume ≥ 140,000 vehicles per day
DIST_5KI	Distance to nearest road with 0 < traffic volume ≤ 10,000 vehicles per day
DIST_15KI**	Distance to nearest road with 10,000 < traffic volume ≤ 20,000 vehicles/day
DIST_25KI	Distance to nearest road with 20,000 < traffic volume ≤ 30,000 vehicles/day
DIST_35KI	Distance to nearest road with 30,000 < traffic volume ≤ 40,000 vehicles/day
DIST_45KI**	Distance to nearest road with 40,000 < traffic volume ≤ 50,000 vehicles/day
DIST_55KI	Distance to nearest road with 50,000 < traffic volume ≤ 60,000 vehicles/day
DIST_65KI	Distance to nearest road with 60,000 < traffic volume ≤ 70,000 vehicles/day
DIST_75KI**	Distance to nearest road with 70,000 < traffic volume ≤ 80,000 vehicles/day
DIST_90KI	Distance to nearest road with 80,000 < traffic volume ≤ 100,000 vehicles/day
DIST_110KI**	Distance to nearest road with 100,000 < traffic volume ≤ 120,000 vehicles/day
DIST_130KI	Distance to nearest road with 120,000 < traffic volume ≤ 140,000 vehicles/day

* Units are m.
** Selected for potential use as a predictor.

Table 1b. Ancillary variables considered for use in prediction - traffic intensity.

Variable name*	Definition
INT125	traffic intensity within 125 m of location
INT250	traffic intensity within 250 m of location
INT500	traffic intensity within 500 m of location
INT1000**	traffic intensity within 1000 m of location
INT1500	traffic intensity within 1500 m of location
INT2000	traffic intensity within 2000 m of location

* All units are vehicles per day / km.
** Selected for potential use as a predictor.

Table 1c. Ancillary variables considered for use in prediction - population.

Variable name*	Definition
POP_DEN**	Population of census tract of location
P_125	Population density within 125 m radius of location
P_250	Population density within 250 m radius of location
P_500	Population density within 500 m radius of location
P_1000	Population density within 1000 m radius of location
UNIT_DEN	Housing unit count of census tract of location
U_125	Housing unit density within 125 m radius of location
U_250	Housing unit density within 250 m radius of location
U_500	Housing unit density within 500 m radius of location
U_1000	Housing unit density within 1000 m radius of location

* Units for the P_ and U_ variables are people per km^2 and units per km^2, respectively.
** Selected for potential use as a predictor.

Table 1d. Ancillary variables considered for use in prediction - distance to point sources.

Variable name*	Definition
VOC1	Distance to source with total VOC emissions > 293,000 lbs/yr
VOC2	Distance to source with 40,000 < total VOC emissions < 143,000 lbs/yr
BEN1**	Distance to source with benzene emissions > 270,000 lbs/yr
BEN2	Distance to source with 80,000 < benzene emissions < 125,000 lbs/yr
ETH1**	Distance to source with ethylbenzene emissions > 4,400 lbs/yr
ETH2	Distance to source with 750 < ethylbenzene emissions < 2,500 lbs/yr
TOL1	Distance to source with toluene emissions >138,000 lbs/yr
TOL2	Distance to source with 43,000 < toluene emissions < 138,000 lbs/yr
TOL3	Distance to source with 1,000 < toluene emissions < 10,000 lbs/yr
XYLENE1	Distance to source with 5,000 < xylene emissions < 21,000 lbs/yr
NOX1**	Distance to source with NO_x emissions >570,000 lbs/yr
NOX2**	Distance to source with 21,000 < NO_x emissions < 221,000 lbs/yr

* Units are m for each variable.
** Selected for potential use as a predictor.

Table 2. Pearson correlations between ancillary variables considered for prediction.

	POP_DEN	INT_1000	DIST_15KI	DIST_45KI	DIST_75KI	DIST_110KI	DIST_140KP	NOX1	NOX2	BEN1	ETH1
POP_DEN	1	-.20	-.30	.10	.04	-.23	-.09	.02	.15	-.02	.04
INT1000	-.14	1	-.34	-.48	-.41	-.44	-.19	-.19	-.17	-.25	.01
DIST_15KI	-.20	-.48	1	.03	-.08	.47	.08	.26	.03	.50	.27
DIST_45KI	.01	-.57	.34	1	.36	.55	.61	.53	.18	.14	-.34
DIST_75KI	.10	-.35	.36	.34	1	.26	-.08	.09	.08	.51	.32
DIST_110KI	-.29	-.58	.64	.45	.48	1	.73	.64	.31	.41	-.29
DIST_140KP	-.31	-.47	.51	.56	.18	.82	1	.79	.39	-.10	-.73
NOX1	-.31	-.40	.38	.55	.30	.72	.76	1	.38	.37	-.26
NOX2	-.13	-.30	.06	.17	.39	.51	.59	.60	1	.06	-.32
BEN1	.07	-.13	.11	.03	.32	.11	-.27	.26	-.09	1	.68
ETH1	.26	.23	-.29	-.33	-.08	-.59	-.86	-.45	-.60	.65	1

Note: Stations selected for passive sampling appear in the upper triangular portion of the matrix (*i.e.*, above the diagonal of 1s); correlations within the group of unmonitored stations appear in the lower triangular portion.

Table 3. Below detection limit (parts per trillion) counts.

Compound	**MDL (pptv)**	**BDL count**	**Nonzero BDL count**
Benzene	27	0	0
Toluene	18	0	0
Ethylbenzene	11	0	0
m,*p*-xylene	27	0	0
o-xylene	13	0	0
4-ethyltoluene	15	9	9
1,3,5-trimethylbenzene	15	1	1
Chlorobenzene	21	133	26
m-dichlorobenzene	20	133	50
p-dichlorobenzene	17	17	17
o-dichlorobenzene	17	131	36
Styrene	21	54	54
1,1-dichloroethane	35	133	0
1,2-dichloroethane	31	19	19
1,1-dichloroethene	11	0	0
cis-1,2-dichloroethene	32	133	7
Trichloroethene	30	133	63
Tetrachloroethene	8	0	0
1,1,1-trichloroethane	15	0	0
Carbon tetrachloride	23	0	0
Freon 113	8	0	0
Freon 114	10	133	0
Freon 11	8	0	0
1,2-dichloropropane	26	133	0
1,3-butadiene	30	0	0

Table 4. Precision estimates. Absolute differences are in parts per trillion (ppt) and ppb for NO_2 and NO.

	Fire Station No. 55		**Hinton TCEQ Site**	
Chemical	**Abs. diff.**	**Abs. % diff.**	**Abs. diff.**	**Abs. % diff.**
Benzene	29.4	16	25.2	17
Toluene	17.4	5	8.4	2
Ethylbenzene	2	4	3.4	6
m,p-xylene	10	6	8.2	5
o-xylene	3.2	6	3	5
4-ethyltoluene	4	19	3	14
1,3,5-trimethylbenzene	3.2	14	2.2	10
Chlorobenzene	0.2	40	1.4	19
m-dichlorobenzene	1	80	2.2	91
p-dichlorobenzene	3.6	16	2.2	10
o-dichlorobenzene	1.6	80	1.2	9
Styrene	3.8	20	4.2	22
1,1-dichloroethane	0	0	0	0
1,2-dichloroethane	2	6	1.2	3
1,1-dichloroethene	0.2	2	0.2	2
cis-1,2-dichloroethene	0	0	0	0
Trichloroethene	2.4	43	3.4	48
Tetrachloroethene	0.4	2	4.6	18
1,1,1-trichloroethane	2	10	1	5
Carbon tetrachloride	28.8	18	28	14
Freon 113	3.2	4	1	1
Freon 114	0	0	0	0
Freon 11	3.4	5	1.4	2
1,2-dichloropropane	0	0	0	0
1,3-butadiene	4.2	10	6.4	13
NO_2	0.7	8	0.6	5
NO	1.6	59	1.8	91

Table 5. Observed mean and median values over all sites and weeks. Units are parts per trillion for VOCs and ppb for NO_2.

Variable	Mean	Median
Benzene	218	225
Toluene	536	539
Ethylbenzene	88	85
m,p-xylene	258	246
o-xylene	87	83
4-ethyltoluene	39	28
1,3,5-trimethylbenzene	45	32
p-dichlorobenzene	32	26
1,2-dichloroethane	38	38
Tetrachloroethene	28	24
1,1,1-trichloroethane	21	21
Carbon tetrachloride	164	159
Freon 113	87	87
1,3-butadiene	75	72
NO_2	12	12
NO_x	16	16

Table 6. Range and selected percentiles of measured ambient levels in Dallas, summer 2006. VOC concentrations are in parts per trillion (ppt) and NO_2 and NO_x are in ppb.

	Percentiles								
Variable	**Min**	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**Max**
Benzene	83	107	113	138	225	276	313	335	388
Toluene	162	267	296	412	539	670	754	797	1166
Ethylbenzene	31	51	54	68	85	104	123	139	190
m,p-xylene	87	147	159	192	246	303	355	423	621
o-xylene	30	50	54	64	83	100	124	142	218
4-ethyltoluene	11	14	17	21	27.5	33	41	46	1068
1,3,5-trimethylbenzene	13	17	20	24	32	41	49	52	1102
p-dichlorobenzene	13	15	16	20	26	33	46	74	171
1,2-dichloroethane	24	27	28	36	38	43	47	49	53
Tetrachloroethene	8	12	13	19	24	33	48	53	87
1,1,1-trichloroethane	15	18	18	19	21	23	23	24	28
Carbon tetrachloride	87	111	118	139	159	192	206	222	350
Freon 113	62	82	83	85	87	90	92	92	94
1,3-butadiene	37.5	42	46	58	72	87	112	123	149
NO_2	3.8	6.3	7.1	9.5	11.8	14.5	17	18.9	25.3
NOx	6	10	11.2	13	16.1	19.2	22.5	24	34.5

Table 7. Final predictive equations. Bold indicates significance at the five percent level.

Regression Equation	R^2 (%)
Benzene = **230.9** – 0.028*DIST15K – **0.0045*DIST75K** + 5.9E-4*DIST110K + **9.1E-5*INT1000**;	72
ln Toluene = **6.8** – 3.2E-5*DIST75K – 8.7E-6*DIST110K - **1.9E-5*NOX1** + 3.5E-6*NOX2;	41
ln Ethylbenzene = **4.9** – 1.1E-5*DIST75K – **4.0E-5*DIST110K** – 1.8E-7*INT1000 – **2.6E-5*BEN1** + 7.9E-6*NOX1 – 1.4E-5*NOX2	63
ln m,p-xylene = -1.6 + 4.1E-5*DIST15K – 1.3 E-5*DIST75K + 3.8 E-6 DIST110K + 2.5E-7*INT1000 – **5.9E-5*BEN1** + **0.76*ln_ETH1** + **1.4E-5*NOX1**	71
ln o-xylene = **4.7** – 2.0E-5*DIST75K - **3.8E-5*DIST110K** - **1.5E-5*BEN1** + 5.1E-6*NOX1	46
4-ethyltoluene = **38.5** – **0.0075*DIST75K** + **0.0017*BEN1**	65
1,3,5-trimethylbenzene = **45.3** – 5.2E-4*BEN1	2
ln p-dichlorobenzene = **3.8** + **4.2E-5*POP_DEN** – **2.2E-5*NOX1**	7
ln 1,2-dichloroethane = **4.1** + **1.5E-5*DIST110K** – 1.8E-6*DIST140KPL – 0.045*ln_ETH1 - 6.1E-7*NOX1 – 4.8E-6*NOX2	47
ln Tetrachloroethene = **3.6** – 4.5E-5*DIST45K – **6.4E-5*DIST75K** + **7.1E-5*DIST110K** + **2.8E-5*ETH1** – **3.9E-5*NOX1** - 5.0E-7*NOX2;	28
1,1,1-trichloroethane = **24.1** – 3.7E-5*DIST140KPL + 9.1E-6*BEN1 – **1.1E-4*ETH1**	84
Carbon tetrachloride = **284.8** + **0.0052*DIST45K** + 2.1E-4*DIST110K + 6.7E-4*DIST140KPL - 1.6E-4*BEN1 – 12.7*ln_ETH1 - 3.1E-4*NOX1 – 5.6E-4*NOX2	96
Freon 113 = **92.5** – 4.0E-5*DIST140KPL – 1.1E-4*BEN1 – 1.7E-4*ETH1	54
ln 1,3-butadiene = **4.6** – 4.6E-6*DIST75K – 1.8E-5*DIST110K - **1.1E-5*BEN1** – 8.2E-6*NOX2	26
ln NO2 **= 2.6** + **4.2E-5*DIST45K** – **2.5E-5*DIST75K** + **1.2E-6*INT1000** – **1.5E-5*BEN1**	34

Table 8. Observed and predicted values at the Hinton site. Difference=Predicted-Observed; % Difference= Difference/Observed.

Pollutant	**Measured**	**Predicted**	**Difference**	**% difference**
Benzene	133	243	110	83
Toluene	494	653	159	32
Ethylbenzene	61	119	58	94
m,*p*-xylene	178	357	179	101
o-xylene	60	109	49	83
4-ethyltoluene	29	42	13	46
1,3,5-trimethylbenzene	29	42	14	47
p-dichlorobenzene	20	31	11	54
1,2-dichloroethane	38	38	0	-1
Tetrachloroethene	25	32	7	27
1,1,1-trichloroethane	21	21	0	0
Carbon tetrachloride	165	165	0	0
Freon 113	89	88	-1	-2
1,3-butadiene	48	90	42	89
NO_2	12	15	3	24

APPENDIX A. Observed and Predicted Differences by Site.

Difference = Predicted- Measured

%Difference =Difference/Measured

Table A1. Fire Station No. 16.

chemical	Measured	Predicted	Difference	%difference
Benzene	271	224	-47	-17
Toluene	638	600	-38	-6
Ethylbenzene	114	107	-7	-6
m,p-xylene	349	359	9	3
o-xylene	116	96	-20	-17
4-ethyltoluene	36	34	-2	-6
1,3,5-trimethylbenzene	41	44	3	7
p-dichlorobenzene	21	30	8	37
1,2-dichloroethane	41	40	-1	-2
Tetrachloroethene	38	34	-4	-11
1,1,1-trichloroethane	22	22	0	0
Carbon tetrachloride	179	175	-4	-2
Freon 113	89	89	0	0
1,3-butadiene	72	83	11	15
NO2	12	13	2	17

Table A2. Fire Station No. 52.

chemical	Measured	Predicted	Difference	%difference
Benzene	137	189	53	39
Toluene	381	458	77	20
Ethylbenzene	64	82	18	28
m,p-xylene	194	209	15	8
o-xylene	68	77	8	12
4-ethyltoluene	27	10	-18	-66
1,3,5-trimethylbenzene	45	42	-3	-7
p-dichlorobenzene	39	28	-12	-30
1,2-dichloroethane	42	42	0	0
Tetrachloroethene	22	21	-1	-5
1,1,1-trichloroethane	22	22	0	0
Carbon tetrachloride	198	182	-17	-9
Freon 113	88	89	1	1
1,3-butadiene	61	72	11	18
NO2	11	11	0	0

Table A3. Fire Station No. 49.

chemical	Measured	Predicted	Difference	%difference
Benzene	159	205	46	29
Toluene	304	443	140	46
Ethylbenzene	51	71	20	39
m,p-xylene	144	158	14	10
o-xylene	49	74	25	51
4-ethyltoluene	15	26	11	73
1,3,5-trimethylbenzene	16	40	24	148
p-dichlorobenzene	22	25	3	14
1,2-dichloroethane	43	41	-1	-2
Tetrachloroethene	20	20	0	0
1,1,1-trichloroethane	22	22	0	0
Carbon tetrachloride	173	175	2	1
Freon 113	90	89	-1	-1
1,3-butadiene	56	66	10	18
NO2	10	12	2	20

Table A4. Fire Station No. 46.

chemical	Measured	Predicted	Difference	%difference
Benzene	171	223	52	30
Toluene	346	428	81	23
Ethylbenzene	68	64	-3	-4
m,p-xylene	193	158	-35	-18
o-xylene	64	70	6	9
4-ethyltoluene	19	43	24	124
1,3,5-trimethylbenzene	24	38	15	64
p-dichlorobenzene	18	21	3	17
1,2-dichloroethane	41	41	1	2
Tetrachloroethene	17	22	5	29
1,1,1-trichloroethane	22	22	0	0
Carbon tetrachloride	166	171	5	3
Freon 113	91	88	-3	-3
1,3-butadiene	62	62	0	0
NO2	10	11	1	10

Table A5. Fire Station No. 25.

chemical	Measured	Predicted	Difference	%difference
Benzene	270	208	-62	-23
Toluene	617	390	-228	-37
Ethylbenzene	87	71	-16	-18
m,p-xylene	259	185	-74	-29
o-xylene	88	71	-17	-19
4-ethyltoluene	28	15	-12	-43
1,3,5-trimethylbenzene	34	38	5	15
p-dichlorobenzene	25	22	-3	-12
1,2-dichloroethane	42	40	-1	-2
Tetrachloroethene	15	15	0	0
1,1,1-trichloroethane	22	22	-1	-5
Carbon tetrachloride	186	183	-4	-2
Freon 113	87	88	1	1
1,3-butadiene	101	65	-36	-36
NO2	12	11	-1	-9

Table A6. Fire Station No. 54.

chemical	Measured	Predicted	Difference	%difference
Benzene	201	166	-36	-18
Toluene	345	347	2	1
Ethylbenzene	62	62	0	0
m,p-xylene	188	187	-2	-1
o-xylene	63	61	-2	-3
4-ethyltoluene	21	12	-8	-39
1,3,5-trimethylbenzene	23	37	13	56
p-dichlorobenzene	19	21	2	11
1,2-dichloroethane	42	42	0	0
Tetrachloroethene	15	16	1	7
1,1,1-trichloroethane	21	21	0	0
Carbon tetrachloride	171	179	8	5
Freon 113	87	87	0	0
1,3-butadiene	66	61	-5	-8
NO2	12	10	-3	-25

Table A7. Fire Station No. 51.

chemical	Measured	Predicted	Difference	%difference
Benzene	214	191	-23	-11
Toluene	413	370	-43	-10
Ethylbenzene	69	61	-8	-12
m,p-xylene	209	214	5	2
o-xylene	71	62	-9	-13
4-ethyltoluene	23	55	32	139
1,3,5-trimethylbenzene	27	34	7	26
p-dichlorobenzene	20	20	-1	-5
1,2-dichloroethane	38	42	4	11
Tetrachloroethene	40	26	-14	-35
1,1,1-trichloroethane	21	20	-1	-5
Carbon tetrachloride	177	173	-4	-2
Freon 113	87	85	-3	-3
1,3-butadiene	68	60	-7	-10
NO2	10	10	0	0

Table A8. Fire Station No. 23.

chemical	Measured	Predicted	Difference	%difference
Benzene	208	216	8	4
Toluene	411	498	88	21
Ethylbenzene	80	95	15	19
m,p-xylene	222	249	27	12
o-xylene	76	95	19	25
4-ethyltoluene	26	36	10	39
1,3,5-trimethylbenzene	30	40	10	33
p-dichlorobenzene	29	25	-4	-14
1,2-dichloroethane	37	38	1	3
Tetrachloroethene	17	17	0	0
1,1,1-trichloroethane	21	22	1	5
Carbon tetrachloride	179	178	-1	-1
Freon 113	86	88	2	2
1,3-butadiene	62	76	14	23
NO2	10	12	2	20

Table A9. Fire Station No. 15.

chemical	Measured	Predicted	Difference	%difference
Benzene	283	235	-48	-17
Toluene	574	561	-13	-2
Ethylbenzene	103	113	9	9
m,p-xylene	297	298	1	0
o-xylene	99	109	10	10
4-ethyltoluene	34	42	8	24
1,3,5-trimethylbenzene	40	42	2	5
p-dichlorobenzene	34	30	-3	-9
1,2-dichloroethane	37	37	1	3
Tetrachloroethene	18	19	1	5
1,1,1-trichloroethane	21	22	0	0
Carbon tetrachloride	169	175	6	4
Freon 113	88	88	1	1
1,3-butadiene	95	83	-12	-13
NO2	14	14	0	0

Table A10. Fire Station No. 53.

chemical	Measured	Predicted	Difference	%difference
Benzene	225	225	0	0
Toluene	592	509	-83	-14
Ethylbenzene	93	80	-13	-14
m,p-xylene	286	245	-41	-14
o-xylene	99	88	-11	-11
4-ethyltoluene	29	60	31	106
1,3,5-trimethylbenzene	39	36	-3	-8
p-dichlorobenzene	27	27	0	0
1,2-dichloroethane	39	37	-2	-5
Tetrachloroethene	27	27	0	0
1,1,1-trichloroethane	21	20	0	0
Carbon tetrachloride	157	152	-5	-3
Freon 113	86	85	-1	-1
1,3-butadiene	77	70	-8	-10
NO2	10	10	0	0

Table A11. Fire Station No. 39.

chemical	Measured	Predicted	Difference	%difference
Benzene	226	218	-8	-4
Toluene	478	474	-5	-1
Ethylbenzene	79	69	-11	-14
m,p-xylene	230	232	2	1
o-xylene	77	77	0	0
4-ethyltoluene	22	49	27	123
1,3,5-trimethylbenzene	25	35	10	39
p-dichlorobenzene	24	24	0	0
1,2-dichloroethane	37	38	1	3
Tetrachloroethene	32	29	-4	-12
1,1,1-trichloroethane	19	20	1	5
Carbon tetrachloride	150	150	0	0
Freon 113	84	85	1	1
1,3-butadiene	61	65	3	5
NO2	9	10	0	0

Table A12. Fire Station No. 55.

chemical	Measured	Predicted	Difference	%difference
Benzene	175	189	14	8
Toluene	393	490	98	25
Ethylbenzene	66	81	15	23
m,p-xylene	183	254	71	39
o-xylene	62	82	20	32
4-ethyltoluene	21	17	-4	-19
1,3,5-trimethylbenzene	23	37	15	66
p-dichlorobenzene	19	29	10	53
1,2-dichloroethane	36	37	1	3
Tetrachloroethene	20	24	4	20
1,1,1-trichloroethane	21	21	0	0
Carbon tetrachloride	152	152	0	0
Freon 113	83	86	2	2
1,3-butadiene	41	72	31	75
NO2	9	10	1	12

Table A13. Fire Station No. 8.

chemical	Measured	Predicted	Difference	%difference
Benzene	292	217	-74	-25
Toluene	788	560	-228	-29
Ethylbenzene	115	103	-11	-10
m,p-xylene	328	294	-33	-10
o-xylene	110	100	-10	-9
4-ethyltoluene	40	40	0	0
1,3,5-trimethylbenzene	45	40	-6	-13
p-dichlorobenzene	46	36	-10	-22
1,2-dichloroethane	36	37	1	3
Tetrachloroethene	24	24	0	0
1,1,1-trichloroethane	20	21	1	5
Carbon tetrachloride	161	160	0	0
Freon 113	84	87	2	2
1,3-butadiene	118	81	-37	-31
NO2	13	12	-1	-8

Table A14. Fire Station No. 3.

chemical	Measured	Predicted	Difference	%difference
Benzene	237	247	11	5
Toluene	544	579	35	6
Ethylbenzene	87	107	20	23
m,p-xylene	257	318	62	24
o-xylene	86	108	22	26
4-ethyltoluene	31	49	18	58
1,3,5-trimethylbenzene	34	40	6	17
p-dichlorobenzene	27	28	0	0
1,2-dichloroethane	36	37	1	3
Tetrachloroethene	34	24	-10	-30
1,1,1-trichloroethane	20	21	1	5
Carbon tetrachloride	159	159	0	0
Freon 113	87	87	0	0
1,3-butadiene	76	83	7	9
NO2	15	15	0	0

Table A15. Fire Station No. 36.

chemical	Measured	Predicted	Difference	%difference
Benzene	244	200	-44	-18
Toluene	700	589	-111	-16
Ethylbenzene	162	120	-42	-26
m,p-xylene	507	379	-128	-25
o-xylene	174	106	-68	-39
4-ethyltoluene	41	31	-10	-24
1,3,5-trimethylbenzene	47	44	-3	-6
p-dichlorobenzene	28	30	2	7
1,2-dichloroethane	36	39	3	8
Tetrachloroethene	22	26	4	19
1,1,1-trichloroethane	22	21	0	0
Carbon tetrachloride	166	174	7	4
Freon 113	91	89	-3	-3
1,3-butadiene	92	87	-5	-5
NO2	14	13	0	0

Table A16. Fire Station No. 30.

chemical	Measured	Predicted	Difference	%difference
Benzene	177	201	24	14
Toluene	734	728	-6	-1
Ethylbenzene	91	92	1	1
m,p-xylene	261	255	-6	-2
o-xylene	85	91	6	7
4-ethyltoluene	28	49	20	70
1,3,5-trimethylbenzene	30	38	8	27
p-dichlorobenzene	37	39	2	5
1,2-dichloroethane	38	38	0	0
Tetrachloroethene	29	52	23	80
1,1,1-trichloroethane	19	21	2	11
Carbon tetrachloride	145	158	13	9
Freon 113	82	86	4	5
1,3-butadiene	75	81	6	8
NO2	9	11	2	21

Table A17. Fire Station No. 43.

chemical	Measured	Predicted	Difference	%difference
Benzene	150	229	79	53
Toluene	692	689	-3	0
Ethylbenzene	95	95	0	0
m,p-xylene	281	279	-2	-1
o-xylene	91	92	2	2
4-ethyltoluene	23	41	18	78
1,3,5-trimethylbenzene	28	40	12	43
p-dichlorobenzene	30	49	20	68
1,2-dichloroethane	40	38	-2	-5
Tetrachloroethene	56	45	-11	-20
1,1,1-trichloroethane	21	21	-1	-5
Carbon tetrachloride	161	161	0	0
Freon 113	89	86	-3	-3
1,3-butadiene	69	82	12	17
NO2	12	12	0	0

Table A18. Fire Station No. 6.

chemical	Measured	Predicted	Difference	%difference
Benzene	304	241	-63	-21
Toluene	656	560	-96	-15
Ethylbenzene	111	103	-7	-6
m,p-xylene	317	296	-21	-7
o-xylene	106	105	-1	-1
4-ethyltoluene	34	52	18	53
1,3,5-trimethylbenzene	39	40	1	3
p-dichlorobenzene	29	25	-4	-14
1,2-dichloroethane	37	37	0	0
Tetrachloroethene	23	23	0	0
1,1,1-trichloroethane	22	21	-1	-5
Carbon tetrachloride	176	157	-19	-11
Freon 113	87	87	0	0
1,3-butadiene	116	80	-36	-31
NO2	18	13	-5	-27

Table A19. Fire Station No. 18.

chemical	Measured	Predicted	Difference	%difference
Benzene	249	259	10	4
Toluene	555	588	33	6
Ethylbenzene	112	112	0	0
m,p-xylene	330	339	9	3
o-xylene	111	111	0	0
4-ethyltoluene	39	46	7	18
1,3,5-trimethylbenzene	46	41	-4	-9
p-dichlorobenzene	23	26	3	13
1,2-dichloroethane	40	37	-3	-8
Tetrachloroethene	39	24	-15	-38
1,1,1-trichloroethane	22	21	-1	-4
Carbon tetrachloride	160	160	1	1
Freon 113	88	88	-1	-1
1,3-butadiene	86	86	0	0
NO2	15	17	2	13

Table A20. Fire Station No. 20.

chemical	Measured	Predicted	Difference	%difference
Benzene	274	240	-33	-12
Toluene	600	626	26	4
Ethylbenzene	94	79	-15	-16
m,p-xylene	270	231	-39	-14
o-xylene	90	86	-4	-4
4-ethyltoluene	26	39	13	50
1,3,5-trimethylbenzene	30	36	6	20
p-dichlorobenzene	36	35	-1	-3
1,2-dichloroethane	39	37	-2	-5
Tetrachloroethene	39	39	0	0
1,1,1-trichloroethane	21	20	0	0
Carbon tetrachloride	160	147	-13	-8
Freon 113	87	85	-2	-2
1,3-butadiene	83	76	-7	-8
NO2	11	13	2	18

Table A21. Fire Station No. 22.

chemical	Measured	Predicted	Difference	%difference
Benzene	244	244	0	0
Toluene	504	638	134	27
Ethylbenzene	83	87	4	5
m,p-xylene	238	238	0	0
o-xylene	95	91	-4	-4
4-ethyltoluene	315	67	-248	-79
1,3,5-trimethylbenzene	352	35	-317	-90
p-dichlorobenzene	20	30	10	49
1,2-dichloroethane	39	38	-1	-3
Tetrachloroethene	24	44	20	83
1,1,1-trichloroethane	21	20	0	0
Carbon tetrachloride	154	143	-11	-7
Freon 113	88	84	-3	-3
1,3-butadiene	91	78	-13	-14
NO2	20	12	-8	-41

Table A22. Fire Station No. 29.

chemical	Measured	Predicted	Difference	%difference
Benzene	149	225	76	51
Toluene	358	557	199	56
Ethylbenzene	59	80	21	36
m,p-xylene	163	209	47	29
o-xylene	54	84	31	58
4-ethyltoluene	18	62	44	241
1,3,5-trimethylbenzene	19	34	14	73
p-dichlorobenzene	23	31	8	35
1,2-dichloroethane	38	37	-1	-3
Tetrachloroethene	31	37	6	19
1,1,1-trichloroethane	19	20	1	5
Carbon tetrachloride	141	147	6	4
Freon 113	81	83	2	2
1,3-butadiene	50	72	23	46
NO2	7	10	3	45

Table A23. Fire Station No. 37.

chemical	Measured	Predicted	Difference	%difference
Benzene	226	224	-2	-1
Toluene	689	533	-156	-23
Ethylbenzene	93	88	-5	-5
m,p-xylene	266	256	-10	-4
o-xylene	88	90	2	2
4-ethyltoluene	28	21	-6	-22
1,3,5-trimethylbenzene	33	37	5	15
p-dichlorobenzene	60	36	-24	-40
1,2-dichloroethane	36	37	1	3
Tetrachloroethene	28	24	-4	-14
1,1,1-trichloroethane	21	21	0	0
Carbon tetrachloride	149	151	1	1
Freon 113	89	86	-3	-3
1,3-butadiene	77	77	0	0
NO2	14	12	-2	-14

Table A24. Fire Station No. 27.

chemical	Measured	Predicted	Difference	%difference
Benzene	216	225	10	5
Toluene	595	574	-21	-4
Ethylbenzene	95	84	-11	-12
m,p-xylene	276	275	-1	0
o-xylene	87	83	-3	-3
4-ethyltoluene	27	27	0	0
1,3,5-trimethylbenzene	30	39	9	30
p-dichlorobenzene	137	32	-105	-77
1,2-dichloroethane	38	39	1	3
Tetrachloroethene	41	37	-4	-10
1,1,1-trichloroethane	21	21	0	0
Carbon tetrachloride	146	151	6	4
Freon 113	86	86	0	0
1,3-butadiene	77	76	-1	-1
NO2	14	11	-3	-21

Part II.

Passive Monitoring of VOCs and NO_2 in Dallas, Texas
Winter, 2008

Presented below are several tables that report summary statistics from the passive monitoring of certain volatile organic carbon species (VOCs) and nitrogen dioxide, NO_2, during the winter of 2008 in Dallas, Texas. Five week-long samples were collected at twenty-five sites within Dallas. Twenty-four samplers were located at fire stations, and one was collocated with a continuous monitor. Sampling was initiated on January 22, 2008 and concluded on February 26, 2008. This effort was a follow-up to a passive monitoring study conducted in the summer of 2007.

The winter study utilized the same sampling methods (Carbopack X tubes for VOCs and Ogawa badges for NO_2) as did the summer study, and the winter study returned to exactly the same monitoring locations. The same quality assurance procedures were followed in each study, and are reported in the Quality Assurance Project Plan, or QAPP (Alion Science & Technology, 2006). This QAPP and the references cited therein include details on the sampling methodology. Details regarding the site selection are found in the report for the summer study (Smith *et al.*, 2007), including discussion of predictor variables that were used in estimating land use regression (LUR) models for each season.

The major difference between the summer and winter studies was that the number of species monitored was reduced for the winter season. To reduce costs, certain species that were frequently at low levels during the summer period were eliminated from the winter study. This resulted in nine VOCs being monitored for winter, as opposed to twenty-five for summer. (Many of the compounds deleted were chlorinated VOCs.) While the summer monitoring reported NO and NO_x together with NO_2, only the latter was recorded for the winter study.

To facilitate comparison with the summer results, the tables below all use the same number as applied in the summer report (Smith *et al.*, 2007). The exception to this is that two additional tables are given here. These are Tables 9 and 10 and report the results of comparisons of summer and winter values by city section.

Table 3 presents the summary of the observed below detection limit (BDL) counts. (*n. b.*, Table 3 also provides an exhaustive list of the VOCs monitored during the winter season.) (Table 1 and 2 not included in winter study.). There were a few more BDL counts in winter for 1,3-butadiene, toluene, and 1,3,5-trimethylbenzene, though none of these exceed 9% of the total number of samples. There were considerably fewer BDL samples for styrene in winter (6% vs. 41%). The other VOCs had similar counts of BDL samples between winter and summer.

Table 4 provides precison estimates for the winter season based on duplicate sampling at two of the sites. On a percentage basis, the precision was slightly better for benzene and styrene in the winter, but was worse for 1,3-butadiene. Relative to the summer results, precision for ethylbenzene, *o*-xylene, and *m,p*-xylene was worse at one

duplicate sampling site (Hinton) and comparable at the other. The other precision estimates were similar between the two seasons.

Table 5 presents the overall (all sites and all weeks) mean and median values for each species monitored during the winter period. Table 6 presents the overall percentiles for each species. The values were generally observed to be higher in the winter than the summer for most species. In terms of the means, this increase was particularly noticeable for benzene and 1,3-butadiene (67% and 63% increases, respectively) and styrene which in summer was often below its detection limit. The two exceptions to this wintertime increase were for 4-ethyltoluene and 1,3,5-trimethylbenzene which exhibited decreases in their means of 6% and 12%, respectively.

Table 7 presents the results of the LUR model for the winter data. Exactly the same equation was fit to the winter values as was used fort he summer regressions. That is, no predictor variables were either added or deleted from the regression equation for any chemical species. There were both similarities and differences between the summer and winter results both in terms of which predictors were found to be significant and the performance of the regression as measured in terms of R^2. Relative to the summer results, both benzene and NO_2 "lost" two predictors (in terms of significance at the 5% level) while 1,3-butadiene "gained" two. Similarly, toluene, *o*-xylene, and 1,3,5-trimethylbenzene, all "added" a significant predictor, while ethylbenzene and *m,p*-xylene both "dropped" one. There was no change in the significant predictors for 4-ethyltoluene.

In terms of the R^2 values, benzene, ethylbenzene, and *m,p*-xylene, all had noticeably lower R^2's than in summer. Alternatively, NO_2, 1,3-butadiene, 4-ethyltoluene, and 1,3,5-trimethylbenzene all had noticeably higher values, especially the latter two. The R^2 values for toluene and *o*-xylene were approximately the same between summer and winter.

Table 8 presents the results of comparing the winter LUR predictions to the observed values at the Hinton site. (The Hinton site was withheld from the LUR estimation to serve as a validation location.) Relative to summer, the wintertime comparisons at the Hinton site were better for benzene, *o*-xylene, and 4-ethyltoluene, a bit worse for toluene, and much worse for 1,3,5-trimethylbenzene. Results for *m,p*-xylene, ethylbenzene, 1,3-butadiene, and NO_2 were similar between the seasons. (Because of the large fraction of BDL samples, no LUR was reported for styrene during the summer.)

To compare pollutant levels in different large areas of Dallas, the city was divided into three sections: north, central, and south. The fire stations in each section were:

north – 20, 22, 27, 29, 30, 37, 39, 43, 53, and 55

central – 3, 6, 8, 15, and 18

south – 16, 23, 25, 36, 46, 49, 51, 52, and 54.

Table 9 reports the median values for each city section for each season and indicates whether the levels in each section were statistically significantly different (at the 5% level) between the two seasons. The Wilcoxon rank sum test (Hollander and Wolfe, 1973) was utilized for these comparisons. As can be seen from the table, wintertime levels were higher in each section for benzene, and for NO_2 in the north and south sections.

Table 10 reports the results of comparing the city sections to each other within the summer and winter periods. To guard against false positives, these comparisons were done with Dunn's test (Dunn, 1964), but modified as suggested by Hochberg and Tomhane (1987). For both winter and summer, the central section had higher NO_2 levels than either the north or south sections. For benzene, the central section was higher than the north in both seasons, but higher than the south section only in summer.

References:

Alion Science and Technology, 2006, Quality Assurance Project Plan: Region 6 Multi-task Passive Air Toxics Monitoring and Analysis, prepared for Multimedia Planning and Permitting Division, Region 6, U. S. Environmental Protection Agency.

Dunn, O. J., 1964. Multiple comparisons using rank sums. *Technometrics* 6:241-252.

Hochberg, Y. and A. C. Tamhane, 1987. *Multiple Comparison Procedures*. John Wiley & Sons, New York, 450 pp.

Hollander, M and D. A. Wolfe, 1973. *Nonparametric Statistical Methods*. John Wiley & Sons, New York, 503 pp.

Smith, L., L. Liao, and C. Stallings, 2007. *Passive Sampling of Ambient Concentrations of Volatile Organic Compounds and NO_2/NO in Dallas, Texas. Final Report.* Prepared for Multimedia Planning and Permitting Division, Region 6, U. S. Environmental Protection Agency.

Table 3. Winter data -- below detection limit (parts per trillion) counts.

Compound	MDL (pptv)	BDL count	Nonzero BDL count
Benzene	8	0	0
Toluene	25	10	3
Ethylbenzene	8	3	0
*m,p-x*ylene	16	1	1
*o-x*ylene	8	6	3
4-ethyltoluene	21	11	4
1,3,5-trimethylbenzene	15	10	3
Styrene	16	8	0
1,3-butadiene	33	11	5

Table 4. Winter data -- precision estimates. Absolute differences are in parts per trillion (ppt) and ppb for NO_2.

Chemical	Fire Station No. 55		Hinton TCEQ Site	
	Abs. diff.	Abs. % diff.	Abs. diff.	Abs. % diff.
Benzene	8	3	12	4
Toluene	32	7	17	4
Ethylbenzene	3	5	12	15
*m,p-x*ylene	10	6	35	18
*o-x*ylene	4	6	13	16
4-ethyltoluene	5	15	3	9
1,3,5-trimethylbenzene	4	13	4	8
Styrene	4	10	4	14
1,3-butadiene	13	16	23	27
NO_2	0.3	3	0.8	6

Table 5. Winter data -- observed mean and median values over all sites and weeks. Units are parts per trillion for VOCs and ppb for NO_2.

Variable	Mean	Median
Benzene	355	351
Toluene	642	612
Ethylbenzene	101	94
*m,p-x*ylene	285	245
*o-x*ylene	109	102
4-ethyltoluene	37	35
1,3,5-trimethylbenzene	40	38
Styrene	36	35
1,3-butadiene	125	113
NO_2	14	14

Table 6. Range and selected percentiles of measured ambient levels in Dallas, winter 2008. VOC concentrations are in parts per trillion (ppt) and NO_2 are in ppb.

	Percentiles								
Variable	**Min**	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**Max**
Benzene	240	275	285	311	351	393	422	439	538
Toluene	232	327	376	475	612	765	975	1136	1788
Ethylbenzene	40	56	59	73	94	121	150	166	294
*m,p-x*ylene	98	145	158	190	245	336	428	554	895
*o-x*ylene	39	58	63	77	102	134	161	189	279
4-ethyltoluene	11	25	26	30	35	40	52	57	68
1,3,5-trimethylbenzene	18	24	26	31	38	46	58	63	90
Styrene	23	26	27	30	35	41	46	50	70
1,3-butadiene	41	65	72	87	113	154	203	222	314
NO_2	2	10	11	13	14	16	18	20	22

Table 7. Winter data -- final predictive equations. Bold indicates significance at the five percent level.

Regression Equation	R^2 (%)
Benzene = **375.5** + 0.001*DIST15K – 0.004*DIST75K – 0.002*DIST110K + 6.1E-7*INT1000	49
ln Toluene = **7.1 – 2.5E-5*DIST75K** – 8.8E-6*DIST110K - **2.4E-5*NOX1** - 6.1E-6*NOX2	41
ln Ethylbenzene = **5.0** – 1.2E-5*DIST75K – 2.3E-5*DIST110K + 5.0E-8*INT1000 – **2.0E-5*BEN1** + 4.2E-6*NOX1 – 1.3E-5*NOX2	40
ln m,p-xylene = 1.1 + 1.4E-5*DIST15K – 3.3E-5*DIST75K + 1.3 E-5 DIST110K + 1.2E-7*INT1000 – **5.7E-5*BEN1** + **0.50*ln_ETH1** + 9.4E-6*NOX1	40
ln o-xylene = **4.1 – 9.2E-6*DIST75K** - 1**.7E-5*DIST110K** - 2**.6E-5*BEN1** - 9.8E-7*NOX1	37
4-ethyltoluene = **44.0 - 3.4E-4*DIST75K - – 4.9E-4*BEN1**	92
1,3,5-trimethylbenzene = **52.5 – 9.4E-4*BEN1**	69
ln 1,3-butadiene = **5.3 – 5.0E-6*DIST75K – 1.7E-5*DIST110K - 2.2E-5*BEN1 – 1.2E-5*NOX2**	40
ln NO2 **= 2.8** - 2.2E-5*DIST45K – 1.2E-5*DIST75K + **6.3E-7*INT1000** – **1.4E-5*BEN1**	48

Table 8. Winter data -- observed and predicted values at the Hinton site. Difference=Predicted-Observed; % Difference = Difference/Observed.

Pollutant	Measured	Predicted	Difference	% difference
Benzene	289	371	82	28
Toluene	518	792	275	53
Ethylbenzene	71	133	61	86
m,p-xylene	194	399	205	106
o-xylene	67	103	36	53
4-ethyltoluene	39	41	2	6
1,3,5-trimethylbenzene	14	47	33	237
Styrene	31	38	7	24
1,3-butadiene	84	164	79	94
NO_2	14	17	3	25

Table 9. Median concentration values by city section and season based on individual fire stations. VOCs are in pptv and NO_2 is in ppb.

	Benzene	Toluene	Ethylbenzene	*m,p*-xylene	*o*-xylene	NO_2
Winter						
north	**344**	552	90	250	99	**14**
central	**381**	774	136	338	141	16
south	**345**	563	90	238	96	**13**
Summer						
north	220	594	92	264	87	11
central	283	574	111	317	106	15
south	208	411	69	209	71	11

Note: Boldface indicates that the winter values were statistically significantly (5% level) different than the corresponding summer values.

Table 10. Comparison of Dallas city sections within seasons.

	Benzene	Toluene	Ethylbenzene	*m,p*-xylene	*o*-xylene	NO_2
south vs. central						
summer	C > S	ns	ns	ns	ns	C > S
winter	ns	ns	ns	ns	ns	C > S
south vs. north						
summer	ns	ns	ns	ns	ns	ns
winter	ns	ns	ns	ns	ns	ns
north vs. central						
summer	C > N	ns	ns	ns	ns	C > N
winter	C > N	ns	ns	ns	ns	C > N

Note: C > S means that the central section had statistically significantly (5% level) higher concentrations than the south section. Similarly, C > N means that the central section was higher than the north section. “ns” means no significant difference at the 5% level.

Part III.

Monitoring data Summary by Site – Mean values

Summer 2006

Winter 2008

Dallas Summer - Monitoring Mean Values - Page 1

Sequence Number	Fire Station Number	Benzene	Toluene	Ethylbenzene	m_p _Xylene	o_Xylene	1_3_Butadiene	Freon _113	1_2 _Dichloroethane	1_1_1 _Trichloroethane	Carbon _tetrachloride
01	16	270.6	638	114.2	349.4	116	72	89.2	41	22	179.2
02	52	136.6	380.8	64.4	194.2	68.4	60.6	88	41.8	22	198.4
03	49	159	303.6	50.8	144.2	49	55.6	90	42.6	22	173.4
04	46	171.2	346.4	67.6	192.6	63.8	61.6	91	40.6	22	166.4
05	25	270.2	617.4	87.4	259.2	87.8	101.4	86.8	41.6	22.2	186.4
06	54	201.4	345	61.8	188.2	63.4	65.6	87	41.6	21	170.6
07	51	214	412.8	69.4	208.8	70.8	67.8	87.4	37.8	21.2	177
08	23	208.4	410.6	80.2	221.8	76	61.8	85.6	37.2	20.6	179.2
09	15	282.8	574	103.2	297	99.4	95.2	87.6	36.6	21.4	168.8
10	53	224.6	592	92.6	286.4	98.6	77.2	86.4	38.8	20.6	156.8
11	39	225.6	478.2	79.2	230	77	61.4	83.6	37	19.2	149.8
12	55	175.3	392.9	65.6	183.2	61.8	41.3	83.2	36.2	20.6	152
13	8	291.6	787.6	114.6	327.8	110.4	117.8	84.4	35.8	20	160.6
14	3	236.6	543.6	87.4	256.6	86	76	87.2	35.8	20.2	158.6
15	36	243.6	700.4	161.8	507	173.6	92.2	91.2	36	21.8	166.4
16	30	176.6	734.2	90.6	261.4	85	75	82	37.6	18.6	145.4
17	43	150	692	95	281.4	90.8	69.2	89	40	21.4	160.8
18	6	304.4	655.6	110.6	316.8	106	116	87	36.8	22	176.4
19	18	249	555.2	112	330.4	111	85.6	88.2	39.6	22.4	159.6
20	99	132.6	493.8	61.3	178.1	59.7	47.6	89.1	38.4	21.1	164.6
21	20	273.6	600	94	270	90.2	82.8	87	39.4	20.8	159.6
22	22	244.4	503.6	82.6	237.8	95.2	90.6	87.6	39	20.6	154.2
23	29	149.25	358	59	162.5	53.75	49.5	81	38.25	18.5	140.5
24	37	226	689.25	92.5	266.25	87.5	76.75	89	36	20.75	149.25
25	27	215.6	595	95	276.2	86.8	76.6	85.6	37.8	20.8	145.8

Dallas Summer - Monitoring Mean Values - Page 2

Sequence Number	Fire Station Number	Tetrachloroethene	4_Ethyltoluene	1_3_5_Trimethylbenzene	p_Dichlorobenzene	NO2	NOX
01	16	37.6	35.6	41.4	21.4	11.78	14.34
02	52	21.8	27.2	45.4	39.4	11.06	17.12
03	49	19.8	15	16.2	21.8	9.9	13.6
04	46	17.2	19.4	23.6	17.8	10.34	14.52
05	25	14.6	27.8	33.6	24.8	11.68	17.46
06	54	14.8	20.6	23.4	18.8	12.14	15.46
07	51	39.6	23	26.6	20.4	10.1	12.54
08	23	16.8	25.6	30	28.6	10.2	13.32
09	15	18.2	33.8	40.2	33.6	14.28	18.18
10	53	27.4	29.2	38.8	26.6	10.48	14
11	39	32.4	22	25.4	24.4	9.24	15.4
12	55	19.8	20.6	22.8	19	8.68	11.66
13	8	24	39.8	45.4	46	12.96	16.76
14	3	33.6	30.8	34.4	27.2	14.9	20.98
15	36	21.6	41	47	27.6	13.64	19.5
16	30	28.6	28.4	29.8	37	9.4	15.02
17	43	55.8	23.2	27.6	29.6	11.9	17.32
18	6	23	34.2	38.8	29.2	18.42	26.6
19	18	39.4	39.4	45.6	23	15.42	19.68
20	99	25.3	28.7	28.7	20.1	12.46	15.73
21	20	39	26.2	29.8	35.8	11.26	13.9
22	22	24.2	314.6	352.2	20.4	19.64	23.74
23	29	31	18.25	19.25	23	6.62	12.44
24	37	27.75	27.75	32.5	60	14.2	17.22
25	27	40.8	26.8	29.8	137	13.96	16.6

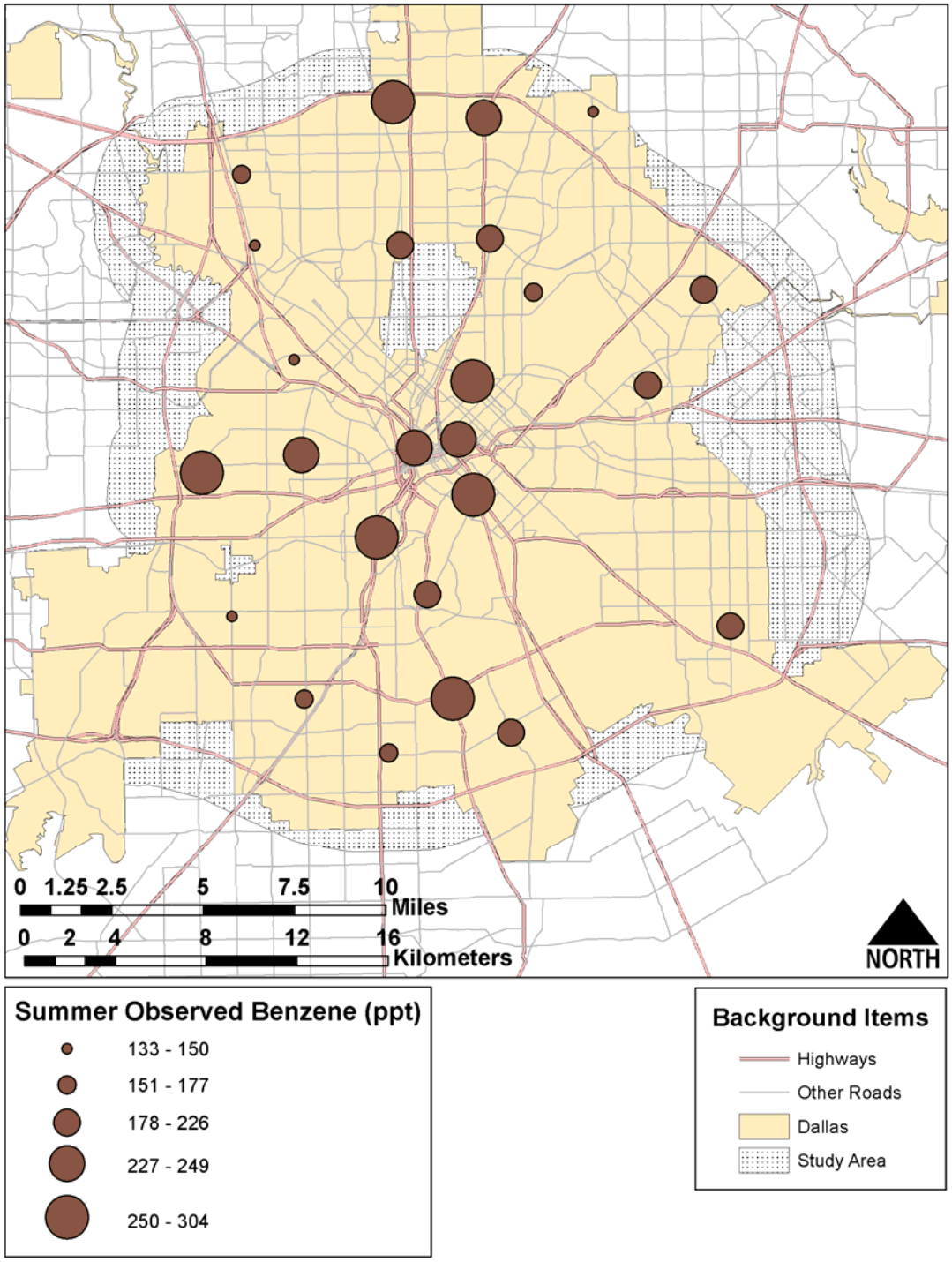
Dallas Winter - Monitoring Mean Values - Page 1

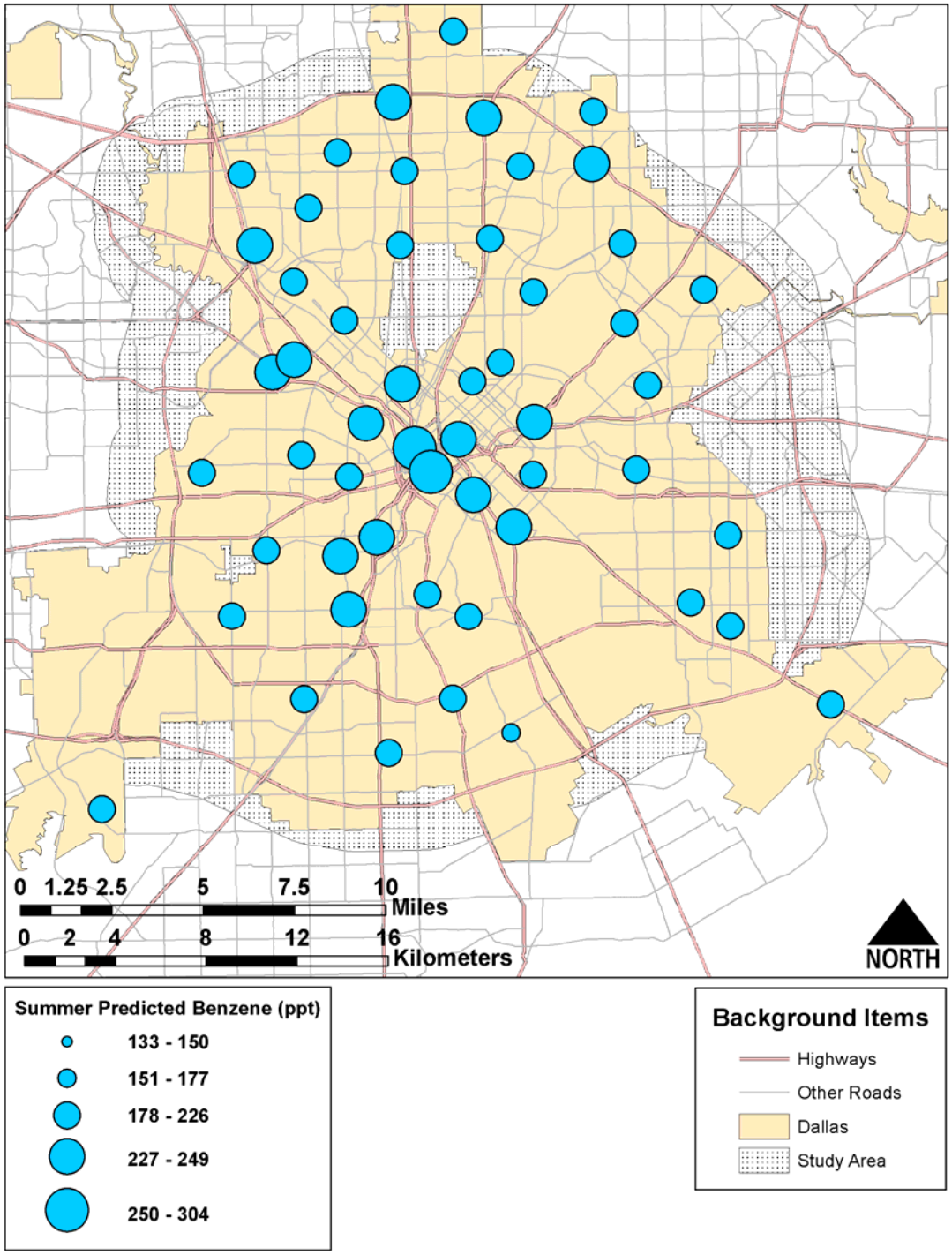
Sequence Number	Fire Station Number	1_3_Butadiene	Benzene	Toluene	Ethylbenzene	m_p_Xylene	Styrene	o_Xylene	4_Ethyltoluene	1_3_5_Trimethylbenzene	NO2
01	16	111.9	350.1	763.7	116.5	374.1	36.2	141.9	44.4	51.0	14.7
02	52	122.9	354.2	572.6	96.6	272.2	35.5	105.6	36.5	38.9	13.0
03	49	99.1	311.2	392.6	63.9	164.1	31.0	67.1	29.0	26.8	13.1
04	46	94.9	345.1	479.9	81.7	217.6	32.2	92.2	34.6	34.4	12.9
05	25	154.9	401.8	595.2	133.5	415.5	36.3	144.1	39.0	42.7	13.2
06	54	97.6	345.0	449.3	76.7	203.2	34.5	82.0	33.5	34.0	14.7
07	51	79.5	300.2	559.0	78.4	217.7	32.1	83.5	31.7	30.2	8.6
08	23	112.5	339.8	563.8	90.5	238.2	36.0	96.1	33.2	36.5	12.4
09	15	149.2	375.6	650.7	105.2	289.5	38.0	108.6	36.9	42.3	16.3
10	3	141.5	381.1	774.9	140.6	431.7	42.4	152.6	48.0	60.9	18.4
11	6	184.2	422.3	776.5	136.2	387.7	44.8	154.4	41.4	48.2	20.0
12	36	179.9	431.6	938.3	172.4	500.9	36.9	181.6	41.9	53.9	15.8
13	30	135.6	368.0	880.8	118.2	323.5	37.1	118.5	36.7	40.9	14.8
14	43	146.2	369.2	825.5	109.5	308.0	36.3	110.8	34.8	38.0	17.0
15	8	203.6	390.2	775.8	145.7	410.3	39.0	141.0	41.1	46.0	14.8
16	18	133.8	361.7	562.0	94.3	261.5	33.7	101.0	38.2	40.4	16.1
17	99	84.4	289.3	517.6	71.3	193.6	30.8	76.4	38.6	42.2	14.0
18	27	139.2	354.9	1127.4	99.3	278.4	37.9	107.8	38.2	41.2	14.5
19	20	118.8	370.2	760.9	115.2	335.9	35.9	149.2	47.4	57.7	12.5
20	22	117.4	325.8	543.1	72.2	196.0	32.7	77.0	31.2	32.8	14.9
21	29	89.4	324.9	456.2	71.7	198.4	32.0	76.9	27.9	28.4	12.6
22	37	123.0	336.4	551.8	85.5	244.7	36.2	98.5	36.3	38.3	15.2
23	53	107.1	347.9	553.2	94.3	255.3	37.6	100.2	34.4	39.1	13.0
24	39	95.0	339.5	534.7	81.9	218.1	39.0	86.1	32.3	32.8	12.8
25	55	78.2	286.2	435.0	71.4	180.9	35.3	73.5	27.8	28.3	11.4

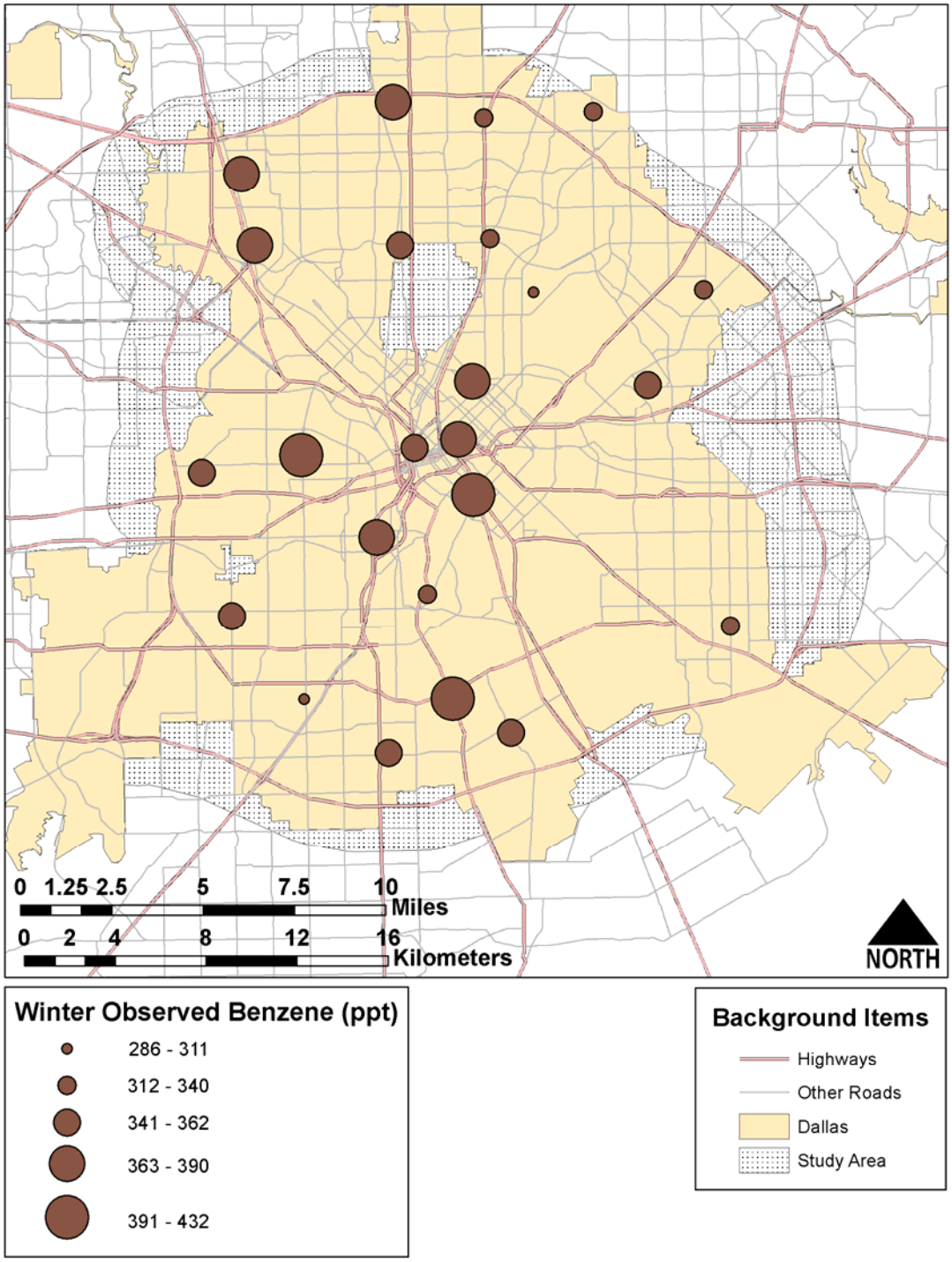
Part IV

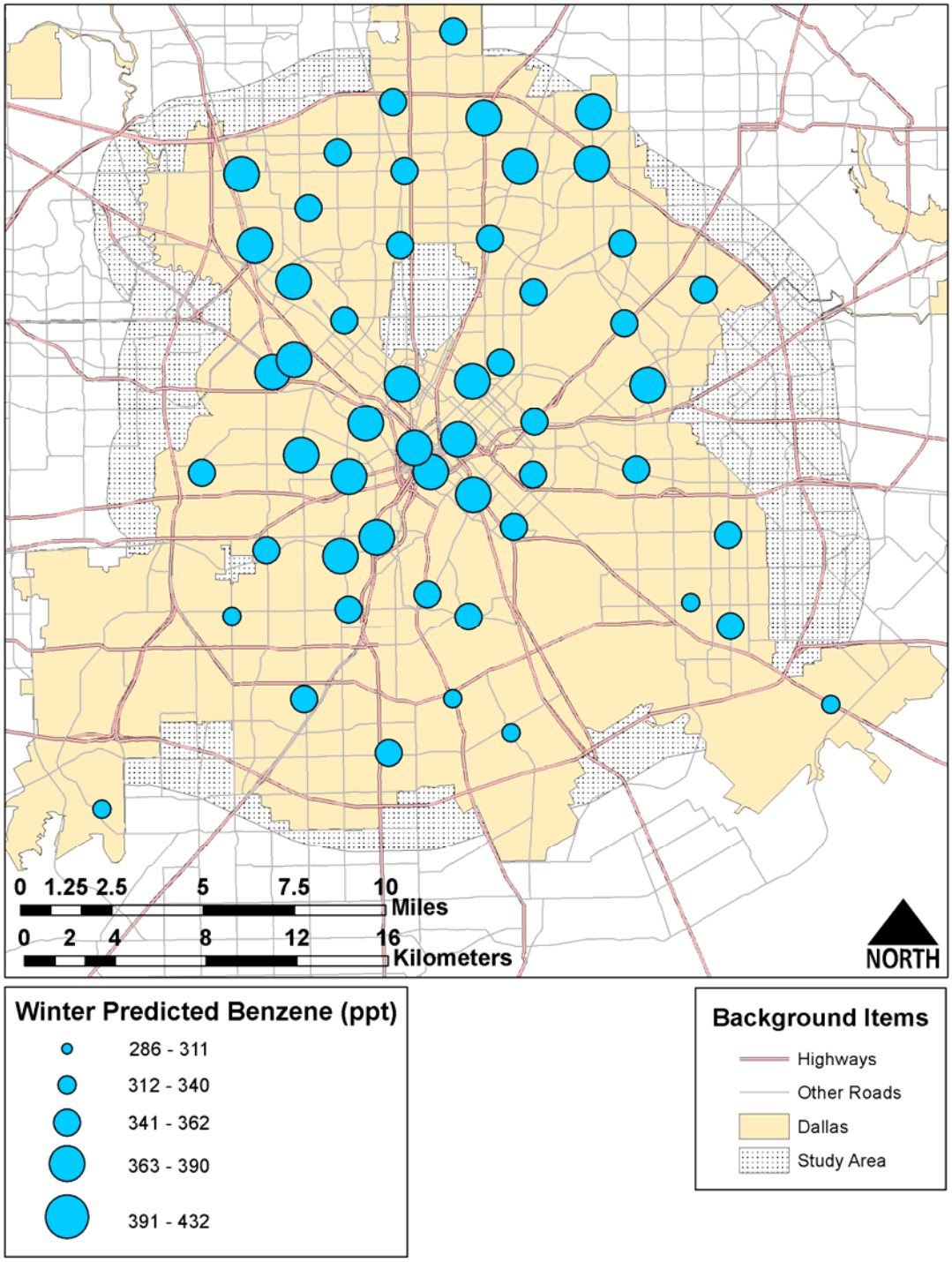
Maps for monitoring and predicted for benzene and NO2

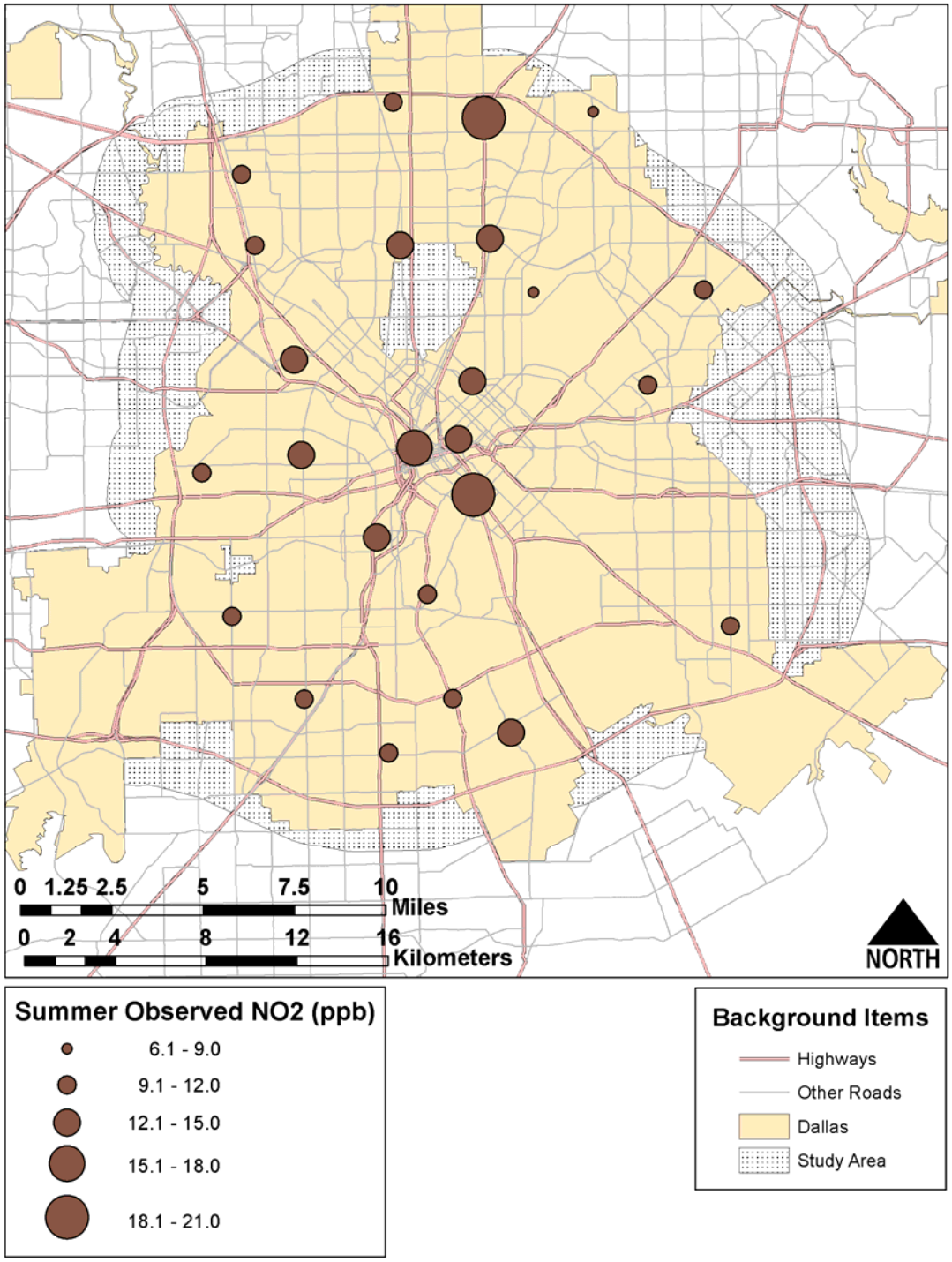
Summer and Winter

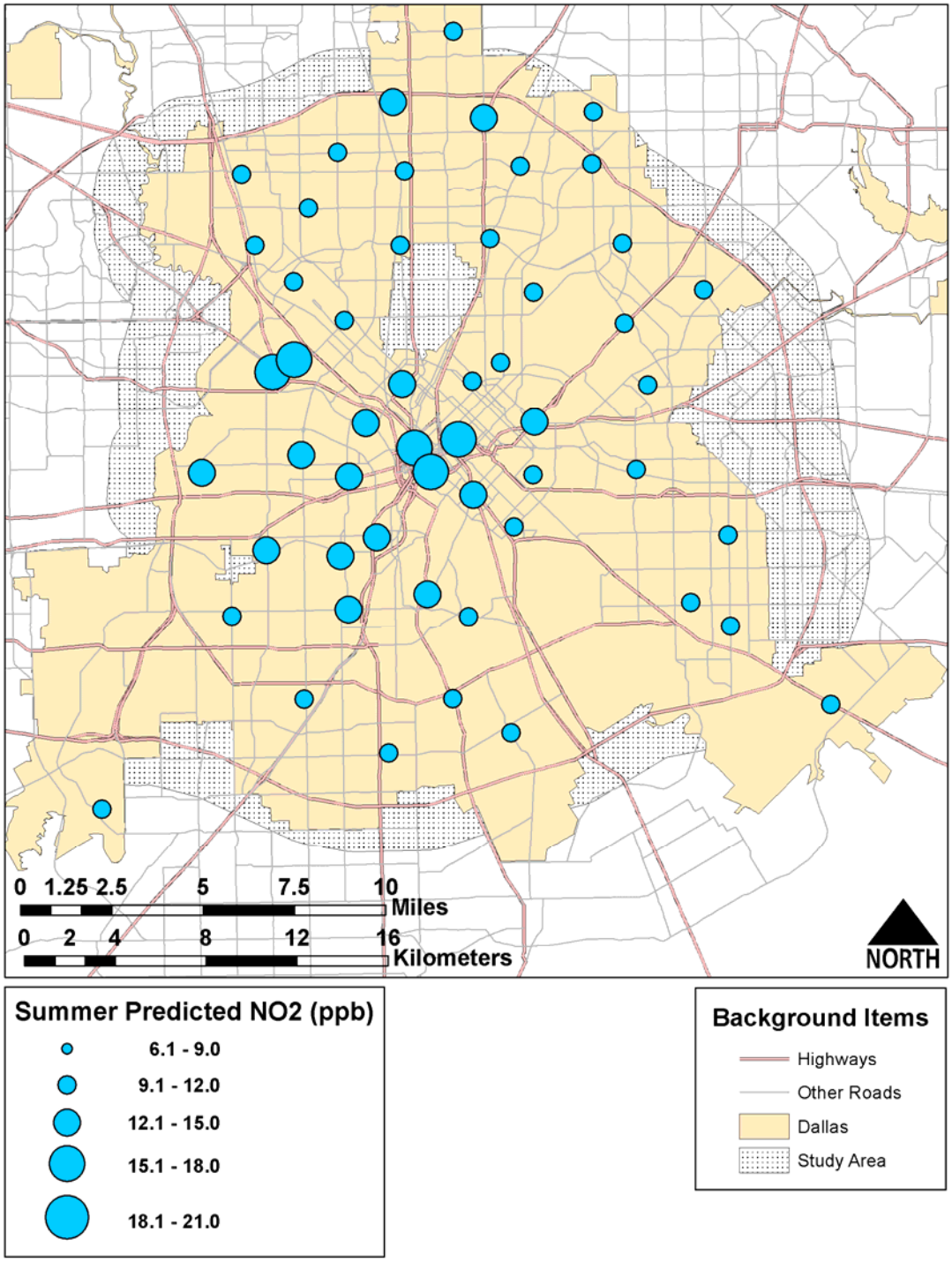

0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Summer Observed Benzene (ppt)
133 - 150
151 - 177
178 - 226
227 - 249
250 - 304
Background Items
Highways
Other Roads
Dallas
Study Area

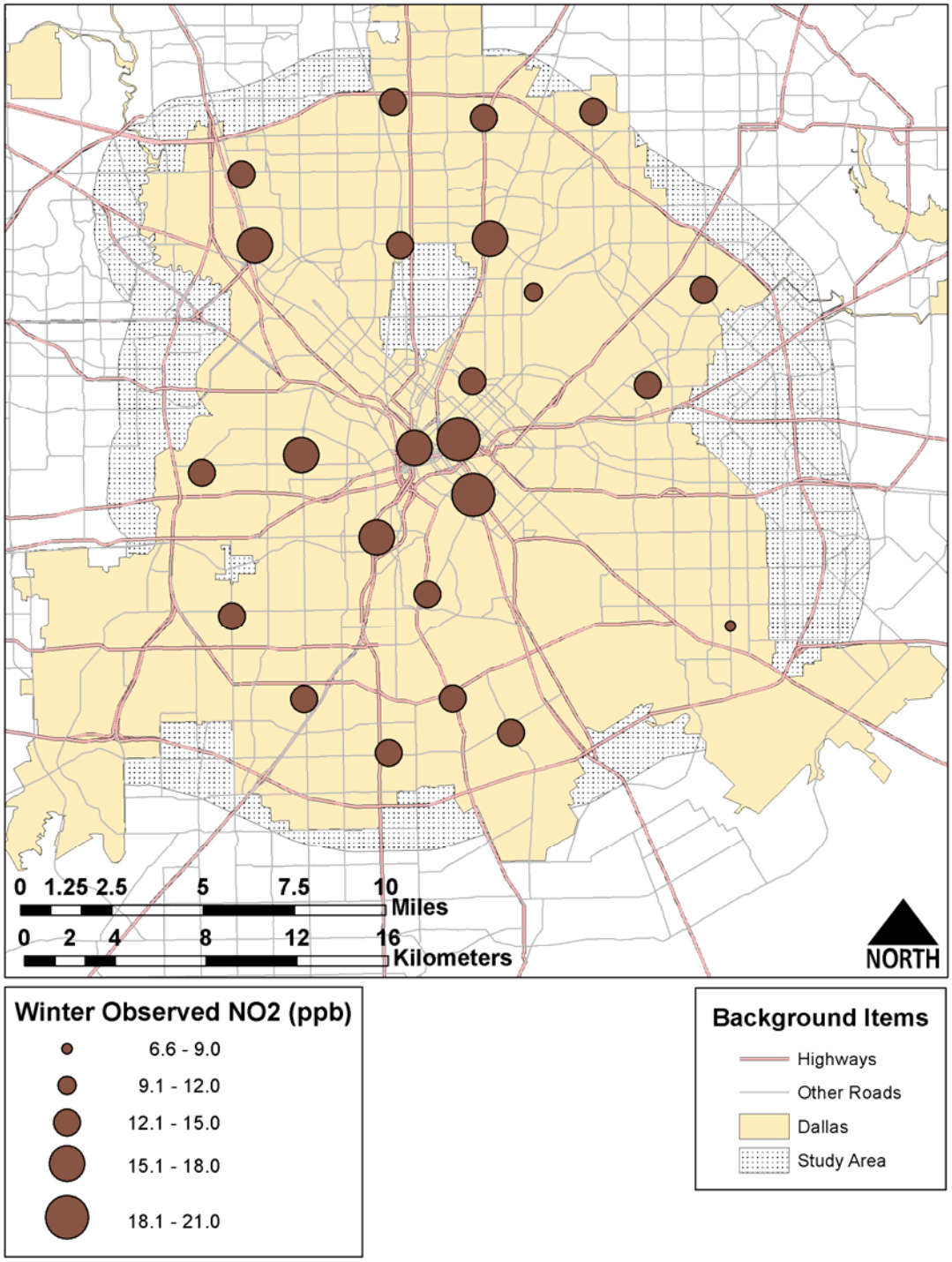

0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Summer Predicted Benzene (ppt)
133 - 150
151 - 177
178 - 226
227 - 249
250 - 304
Background Items
Highways
Other Roads
Dallas
Study Area

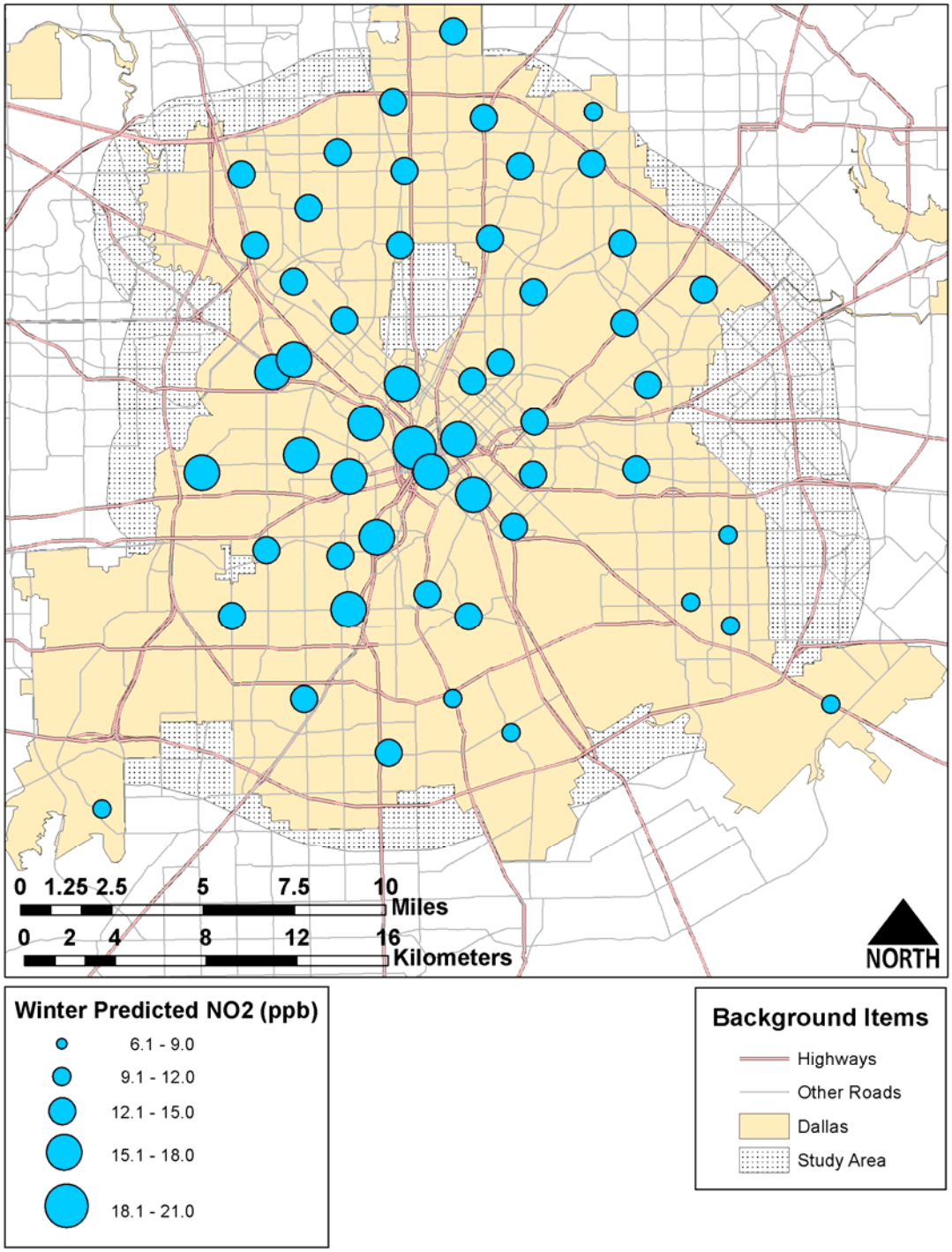

0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Winter Observed Benzene (ppt)
286 - 311
312 - 340
341 - 362
363 - 390
391 - 432
Background Items
Highways
Other Roads
Dallas
Study Area


0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Winter Predicted Benzene (ppt)
286 - 311
312 - 340
341 - 362
363 - 390
391 - 432
Background Items
Highways
Other Roads
Dallas
Study Area


0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Summer Observed NO2 (ppb)
6.1 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 21.0
Background Items
Highways
Other Roads
Dallas
Study Area


0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Summer Predicted NO2 (ppb)
6.1 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 21.0
Background Items
Highways
Other Roads
Dallas
Study Area


0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Winter Observed NO2 (ppb)
6.6 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 21.0
Background Items
Highways
Other Roads
Dallas
Study Area


0 1.25 2.5 5 7.5 10
Miles
0 2 4 8 12 16
Kilometers
NORTH
Winter Predicted NO2 (ppb)
6.1 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 21.0
Background Items
Highways
Other Roads
Dallas
Study Area