



Rhode Island Department of Environmental Management
Office of Air Resources

Characterization of
Ambient Air Toxics in Neighborhoods Abutting T. F. Green Airport
and Comparison Sites

Final Report

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1.0 Introduction

In 2004, the Rhode Island Department of Environmental Management (RI DEM), Office of Air Resources, received a Community Assessments grant from the United States Environmental Protection Agency's (US EPA's) National Air Toxics Monitoring Program to study air quality in neighborhoods abutting TF Green Airport, a medium hub airport located in Warwick, Rhode Island. Sampling was conducted between April 2005 and August 2006 by the RI DEM and the Rhode Island Department of Health (HEALTH) Air Pollution Laboratory.

RI DEM formed an advisory group that met throughout the planning, implementation and data reduction stages of the study and that assisted with presentations of the data to the public. The advisory group consisted of appointees from the Warwick Mayor's office, the Warwick City Council, the Concerned Airport Neighborhoods group and RI DEM as well as representatives from the US EPA, HEALTH and RI DEM. Members included Warwick residents as well as technical experts in health and the environmental issues. The Rhode Island Airport Corporation (RIAC), which is the quasi-state agency that operates TF Green and the other Rhode Island state airports, did not participate in the advisory committee, but supplied airport operation data to RI DEM and allowed RI DEM to site three of the monitoring shelters on RIAC-owned property. The City of Warwick assisted RI DEM in the installation of the shelters and with venues and publicity for meetings and presentations.

The main impetus for the study was concerns of Warwick residents and the Warwick City government about the impact of airport operations on local air quality. This concern was heightened by plans for an extension of the main runway and by an analysis of cancer incidence data released by HEALTH in early 2004 that showed elevated lung cancer rates in several census tracts that are frequently downwind of the Airport. Those data are attached as Appendix A. Due to the long latency period associated with lung cancer, measurements of current air quality cannot be directly linked to recently occurring cancers. However, the study was designed to address local concerns by providing data to characterize current health risks from inhalation of air toxics in Warwick and, to the extent possible, to identify the contribution of the airport and other stationary and mobile sources to those risks.

2.0 Study Objectives

The study was designed with the following objectives:

- Characterize the ambient air toxics levels in neighborhoods around the Airport and a comparison Warwick neighborhood.

- Calculate the cancer and non-cancer risk associated with those pollutant levels and provide those data to HEALTH for further health impact analysis.
- Provide a context for the Warwick air toxics levels by comparing the concentrations of air toxics measured in Warwick with those measured at other Rhode Island locations (a rural site in W. Greenwich, a suburban site in East Providence that is often downwind of the Providence metropolitan area, an urban site in Providence and a Pawtucket site adjacent to Interstate Route 95).
- To the extent possible, determine the impacts of various source types on air toxics levels at the monitoring locations.
 - Characterize the impact of Airport emissions (e.g. taxiing/idling aircraft, aircraft takeoffs, ground equipment, and on-site on-road vehicles such as cars, shuttles and busses).
 - Characterize the contribution of other source types (e.g. industrial and commercial stationary sources and off-site mobile sources).
- Verify model predictions
 - Compare measured concentrations with those predicted in the Environmental Impact Statement analysis prepared for the runway expansion, if air toxics modeling was conducted as part of that project;
 - Compare measured concentrations with those predicted by the US EPA in their National Scale Assessment program.
- Establish a baseline that can be used to evaluate the air quality impacts of planned changes in airport operations, including:
 - Modifications that would increase emissions (e.g. expansion of operations).
 - Modifications that would decrease emissions (e.g. introduction of alternatively fueled ground service equipment, shuttles and buses; shift to cleaner airplanes; possible initiation of railway service to Airport).
 - Identify future monitoring needs and other needed actions.

3.0 Study Design

RI DEM measured air toxics levels at five locations in Warwick during a 17 month period from April 2005 through August 2006. Sampling included a combination of 24-

hour time-integrated samples, short-duration samples during peak emissions periods and real-time measurements using continuous instrumentation.

4.0 Pollutant Selection and Sampling/Analytical Methodology

RI DEM identified target pollutants for the study considering the following:

- Toxic pollutants found in aircraft emissions
- Pollutants that have been associated with elevated risk levels in previous airport studies
- Air toxics emitted by other nearby sources
- Availability of accurate monitoring methods
- Pollutants currently measured at other Rhode Island locations.

After reviewing available literature, RI DEM identified the following pollutants as components of airport emissions that may be associated with elevated neighborhood health risks: benzene, 1,3-butadiene, toluene, naphthalene, formaldehyde, acetaldehyde, acrolein, polycyclic aromatic hydrocarbons (PAHs), diesel particulate and fine particles (PM_{2.5}). Due to methodological limitations, PAHs, acrolein and naphthalene were not measured in this study. The remaining pollutants identified, along with a number of other volatile organic compounds (VOC) associated with mobile and stationary sources were included.

EPA Method TO-15 was used to measure VOC concentrations. In this method, air samples are collected in Summa canisters and are analyzed using a gas chromatograph/mass spectrometer. Note that, while acrolein levels were identified using this method, concentrations of that pollutant are not reported here because of concerns about the acceptability of the use of TO-15 for accurately measuring that pollutant. Carbonyls (acetaldehyde, formaldehyde and acetone) were measured using EPA Method TO-11a, which involves collection on DNPH-treated absorbent material and analysis with High Pressure Liquid Chromatography. Both of these methods produce time-weighted average concentrations.

Aethalometers were used to measure black carbon as an indicator of diesel/jet engine particulate matter. Initially, the aethalometers were operated in a dual-channel mode because previous studies had suggested that a divergence in concurrent readings by the two aethalometer channels (ultraviolet and infrared) is indicative of the presence of PAHs. However, operation in that mode caused excessive data noise, limiting the usefulness of short averaging time data. To remedy that problem, the aethalometers were switched to operating on a single channel in June 2006. This change decreased the data noise, making the black carbon measurements more reliable, but eliminated a potential indicator of PAHs.

RI DEM also operated beta attenuation monitors (BAMs) at two of the sites to continuously measure PM_{2.5} concentrations. At another location, RI DEM operated a Cerex optical beam system for approximately seven months in 2006 in an attempt to

collect continuous measurements of benzene, naphthalene, nitrogen dioxide (NO₂), sulfur dioxide (SO₂), toluene, xylenes, styrene and formaldehyde. Operation of this system did not yield useful data. Discussions of the problems associated with operating the optical system and of the limitations of the data collected by the PM_{2.5} monitors are included in sections 11.0 and 9.2.4 of this document, respectively.

Pollutants successfully monitored in the study are listed in Table 1.

Table 1 Study Pollutants

VOC		
acetylene	2,4-dimethylpentane	a-pinene
acrylonitrile	ethane	propane
benzene	ethyl acetate	propene
1,3-butadiene	ethylbenzene	n-propylbenzene
1-butene	ethylene	styrene
butane	m-ethyltoluene	1,1,2,2-tetrachloroethane
cis-2-butene	o-ethyltoluene	tetrachloroethylene
trans-2-butene	p-ethyltoluene	toluene
carbon disulfide	n-heptane	1,1,1-trichloroethane
carbon tetrachloride	n-hexane	trichloroethylene
chlorobenzene	isobutane	1,2,3-trimethylbenzene
chloroform	isopentane	1,2,4-trimethylbenzene
chloromethane	isoprene	1,3,5-trimethylbenzene
cyclohexane	isopropylbenzene	2,2,4-trimethylpentane
cyclopentane	Methyl-t-butyl-ether	2,3,4-trimethylpentane
n-decane	methyl ethyl ketone	n-undecane
1,2-dibromoethane	methylcyclohexane	vinyl chloride
p-dichlorobenzene	methylcyclopentane	o-xylene
1,1-dichloroethane	2-methylheptane	p & m xylenes
1,2-dichloroethane	3-methylheptane	
1,1-dichloroethene	2-methylhexane	Carbonyls
dichloromethane	3-methylhexane	acetaldehyde
1,2-dichloropropane	2-methylpentane	acetone
cis-1,3-dichloropropene	3-methylpentane	formaldehyde
trans-1,3-dichloropropene	n-nonane	
m-diethylbenzene	n-octane	Black carbon
p-diethylbenzene	pentane	
2,2-dimethylbutane	1-pentene	Fine Particulate Matter (PM_{2.5})
2,3-dimethylbutane	cis-2-pentene	
2,3-dimethylpentane	trans-2-pentene	

5.0 Sampling Locations

The monitors were sited in the following locations, which are shown on Figure I. Locations of the monitors relative to the areas identified by HEALTH as having elevated levels of lung cancer are shown in Figure II.

Site 1 Field View The maximum impact site was located in the yard of an occupied residence on Field View Drive, less than 0.1 miles west of the taxiway to the main runway (Runway 5-23) and less than 0.2 miles northwest of the southwestern end of the runway. Flights taking off on Runway 5 (to the northeast) idle in line in the section of the taxiway closest to the Field View neighborhood while waiting for clearance, and then turn a corner and enter the runway to begin take off. Neighborhood residents reported that they could smell exhaust fumes from taxiing and idling airplanes, especially under relatively stagnant air conditions. Approximately one third of departing flights take off from Runway 5. The site is also 0.1 – 0.2 miles south of airport parking areas.

Lung cancer rates in the census tract that includes Field View Avenue (219.01) were elevated for both genders. VOC, carbonyls, black carbon and PM2.5 were measured at this site.

Site 2 Lydick The second site was located on Lydick Avenue in the Hoxsie neighborhood of Warwick, about 0.5 miles northeast of the northeast end of the main runway. This location is in a census tract, 212, with substantially elevated lung cancer rates. Hoxsie is on the opposite side of the Airport from the Field View Drive area, and thus the two sites form an upwind-downwind pair on days that the wind is from the northeast or southwest.

The Lydick site is potentially impacted by aircraft operations when winds are from the southwest or south-southwest and planes are taking off on Runway 23 (to the southwest). During the study, 55% of departures used that runway. It may also be impacted by automobile traffic from Airport Road, which is approximately 0.25 miles to the south and from Route 117, which is 0.35 miles to the east. Airport Road has an Average Daily Traffic (ADT) count of 36,071. There is also an industrial area approximately 0.25 miles west to west-northwest of the site.

VOC, carbonyls, black carbon and PM2.5 were measured at this site.

Site 3 Fire Station The third site was behind Fire Station #8, off Post Road in the Hillsgrove neighborhood of Warwick, approximately 0.25 miles north-northwest of the northwest end of the airport's secondary runway, 16-34, and slightly more than 0.5 miles northwest of the main runway. The site is 0.57 miles north-northwest of the airport terminal building. According to RI DEM's air pollution inventory, the highest concentration of industrial and commercial stationary air toxics sources in Warwick is in the Jefferson Boulevard area, which is approximately 0.2 miles west of the site.

In addition to Jefferson Blvd, the site is also near two other high traffic roadways, Post Road, which is about 0.07 miles to the east, and Airport Road, which is less than 0.3 miles to the south. In addition, an on-ramp to Rte. 37 is located approximately 0.3 miles northeast of the site. According to the Rhode Island Department of Transportation, the 2006 ADT count for Post Road was 30,100 and that for Airport Road was 33,500.

Therefore, site 3 is potentially impacted by several types of air pollution sources. It is downwind of industrial sources when wind is from the west, northwest or southwest, downwind of busy roadways when the wind is from the south, southeast, east and northeast and downwind of the airport terminal area and runways when the wind is from the southeast and south-southeast.

Site 3 was located in a census tract, 211, that does not have elevated lung cancer rates. VOC, carbonyls and black carbon were measured at this site.

Site 4 Smith St. The fourth site was located off Smith Street between Groveland and Gertrude. The houses formerly located on the lots in this block had been purchased by RIAC and demolished prior to the study, but occupied residences remain in adjacent areas. The site is approximately 0.65 miles south-southwest of the southwest end of the main runway, slightly more than 0.3 miles south of Main Road and slightly more than 0.4 miles east of Post Road Extension. Soccer and softball playing fields are located adjacent to Main Road, approximately 0.15 miles northeast of the site.

Site 4 is approximately 0.7 miles south-southwest of the Field View site (Site 1). It is most likely to be impacted from aircraft traffic when the wind is from the north-northeast and planes are using Runway 5. The census tract in which this site is located, 219.01, has elevated lung cancer rates. Co-located VOC, carbonyls and black carbon measurements were conducted at this site.

Site 5 Draper Ave. The distant site was located across from the Gorton Middle School on Draper Ave., approximately 2.3 miles east-southeast of the southwest end of the main runway. This site is in a census tract, 215.02, with one of the highest lung cancer rates in Warwick and is approximately 0.6 miles west of Narragansett Bay. The advisory committee was interested in this site to investigate the possible impact of sea breezes on pollutant levels near the coast. It has been theorized that a “sea breeze effect” may occur when prevailing winds with a westerly component collide with off-shore sea breezes, resulting in localized areas of stagnation between an emissions source, such as the airport, and the coastline. Pollutants emitted by those sources could be trapped in the stagnated air mass, resulting in elevated localized pollutant levels. VOC, carbonyls and black carbon were measured at this site.

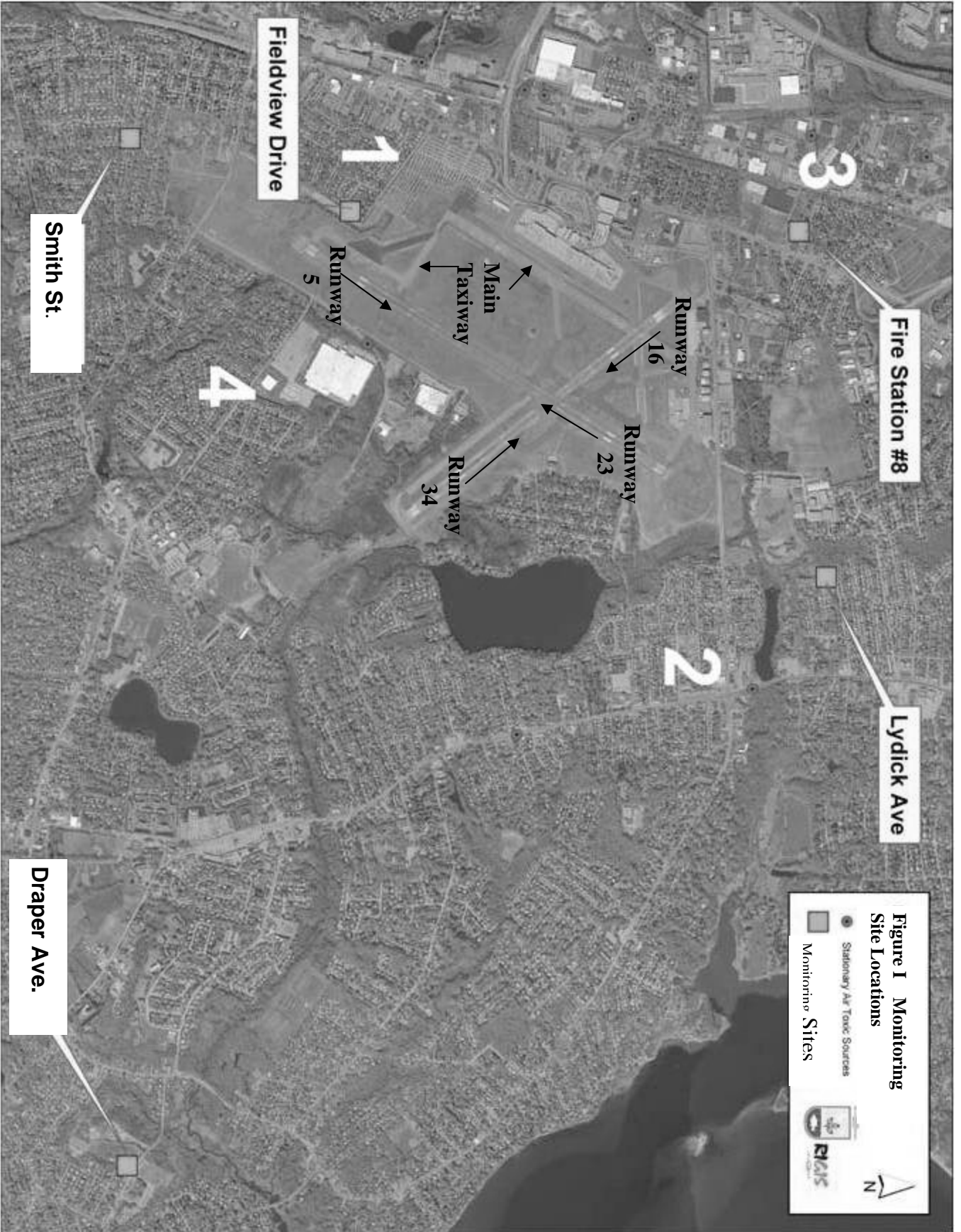
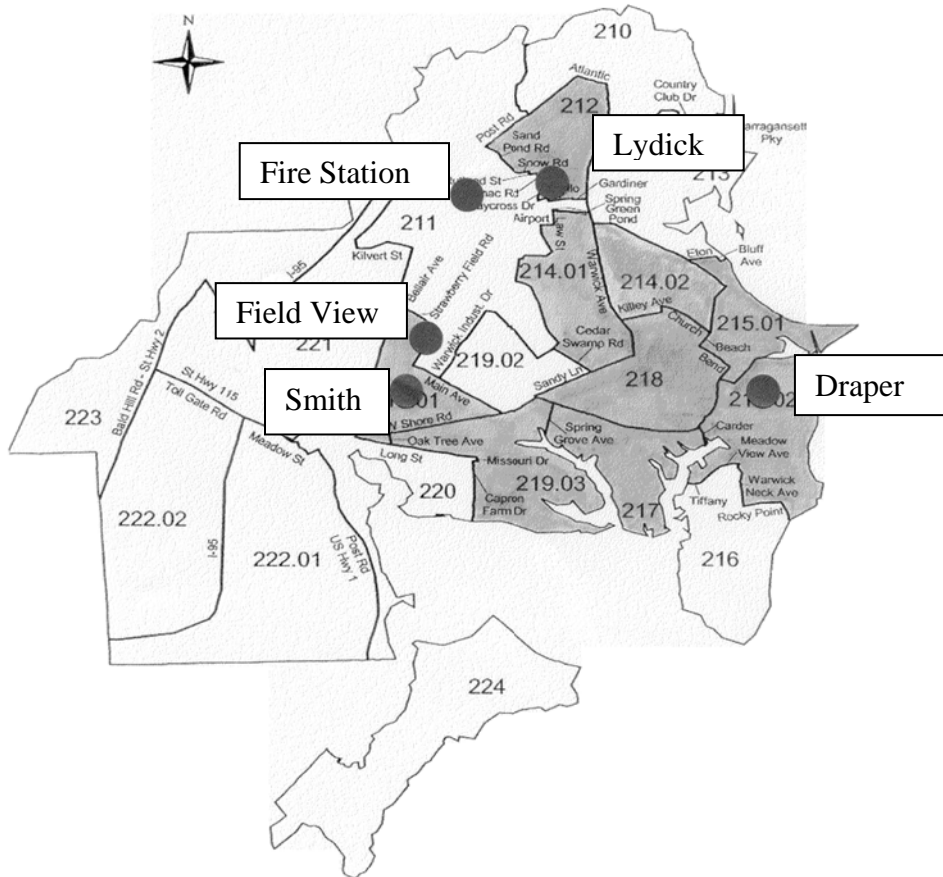


Figure II Locations of Monitoring Sites and Census Tracts with Elevated Lung Cancer Rates
Period of Observation: 1987-2000



According to the HEALTH analysis, lung cancer rates for both genders are elevated relative to the rates in Rhode Island as a whole in the census tracts shaded in the above figure.

6.0 Sampling Frequency and Duration

24-hour VOC samples were collected at all five sites every sixth day from 15 April 2005 to 4 June 2006 (60 – 68 valid samples per site) on the same schedule that VOC samples were collected at the four permanent VOC monitoring sites in the Rhode Island air monitoring network (Providence, E. Providence, Pawtucket, W. Greenwich). In an effort to measure peak levels during a time with heavy airport and roadway traffic, VOC samples were collected every 6th day for 3-hour periods (6:00 – 9:00 am EDT) from 10 June 2006 – 14 September 2006 (13 – 17 valid samples per site). 3-hour VOC samples were concurrently collected at the comparison site in E. Providence during June, July and August of 2006.

24-hour carbonyl samplers were collected every 6th day during the period 16 April 2005 – 27 August 2006. Since some samples collected during the first summer were disqualified due to condensation problems, the 24-hour schedule was maintained through the second summer. In total, 43 valid samples were collected at Draper, where additional data collection issues occurred, and 73 – 77 valid samples were collected at each of the other four sites. Concurrent carbonyl samples were collected at comparison sites in Providence and E. Providence.

Aethalometer measurements were collected continuously at all five sites from 1 May 2005 – 31 August 2006. Data are available for one-minute, five-minute and one-hour averaging periods.

Hourly PM_{2.5} measurements were collected at the Lydick site (Site 2) from 4 May 2005 through 24 August 2006. PM_{2.5} was measured at Site 4 (Smith) from 1 May 2005 – 19 October 2005, at which time the monitor was moved to Site 1 (Field View), where PM_{2.5} monitoring was continued until the end of August 2006.

7.0 Meteorological Measurements

The National Weather Service operates a meteorological station at T.F. Green Airport that measures wind speed, wind direction, dew point, barometric pressure, relative humidity, sky conditions, precipitation and visibility. Hourly data from this site were made available to RI DEM in spreadsheet form at the end of each month during the study period. In addition, meteorological monitoring equipment was operated on the roof of the Gorton Middle School, across the street from Site 5, for most of the study period. Wind speed data are available from that site; however, due to an error in the data logger's mode of averaging wind direction, the wind direction data collected at that site were invalidated.

8.0 Health Benchmarks

Prior to beginning monitoring, RI DEM and HEALTH developed a list of short-term and long-term health benchmarks to be used to evaluate the potential health impacts of measured VOC and carbonyl levels. Short-term benchmarks were based on acute Minimal Risk Levels (MRLs) developed by the Agency for Toxic Substances and Disease Registry (ATSDR) and acute Reference Exposure Levels (RELs) developed by the State of California. When acute values were not available from those sources, occupational levels were used. Short-term health benchmarks were compared to maximum daily measured concentrations to identify potential acute health threats.

Long-term health benchmarks were developed for non-cancer effects and, for known or suspect carcinogens, for cancer effects. Long-term non-cancer benchmarks were based on US EPA inhalation Reference Concentrations (RfCs), ATSDR chronic MRLs and California chronic RELs. Benchmarks for cancer effects were based on inhalation cancer potency factors developed by the US EPA and the State of California. During the data collection period, the concentration corresponding to a risk of 1 in 10,000 (10^{-4} risk level) was used as a trigger for immediate action. In this assessment, the concentrations corresponding to a cancer risk of 1 in one-million (10^{-6} risk level) along with the long-term non-cancer benchmarks were compared to the average concentrations at each site to evaluate long-term health effects.

9.0 Study Results

9.1 Volatile Organic Compounds (VOC) and Carbonyls

As discussed above, 24-hour VOC samples were collected at the five Warwick sites every sixth day between 16 April 2005 and 4 June 2006 (60 – 68 samples total per site). Concurrent VOC samples were collected at four permanent monitoring sites in Rhode Island: an urban site in Providence, a suburban site in East Providence that is often downwind of the metropolitan Providence area, a site in a residential area adjacent to Interstate Route 95 in Pawtucket, and a rural site in W. Greenwich. 3-hour VOC samples (6:00 – 9:00 am EDT) were collected at the Warwick sites every 6th day from 10 June 2006 – 14 September 2006 (13 – 17 total samples per site). 3-hour VOC samples were concurrently collected at a site in E. Providence during June, July and August of 2006.

Collection of 24-hour carbonyls samples also began on 16 April 2005. During the summer of 2005, however, a number of samples were invalidated due to condensation in the sampling lines. Therefore, in order to obtain a full year of valid samples, collection of 24-hour carbonyl samples every 6th day was continued through the end of August 2006. At the Draper site, which experienced additional problems, 43 valid formaldehyde and acetone samples and 39 valid acetaldehyde samples were collected. At the other Warwick sites, 72-77 valid formaldehyde and acetone samples and 69-73 valid acetaldehyde samples were collected. Concurrent carbonyl samples were collected at the E. Providence and Providence sites throughout the sampling period.

Table 2 lists the maximum concentrations measured in the 24-hour VOC and carbonyl and 3-hour VOC samples for each of the pollutants for which an acute health benchmark was available. The acute benchmarks and the ratio of the maximum concentrations to the acute benchmarks are also shown in that table. Note that a ratio greater than 1.0 would indicate that the acute benchmark was exceeded. For all of the pollutants, the maximum concentrations observed were substantially lower than the corresponding acute health benchmarks. The substances that came closest to the acute benchmarks were formaldehyde and benzene. The maximum measured concentrations of those substances at the Warwick sites were 16% and 12%, respectively, of the corresponding acute health benchmarks. The short-term health benchmark for formaldehyde is the ATSDR acute MRL and is based on respiratory health effects. The short-term benchmark for benzene, also the acute MRL, is based on immunological effects.

Table 2 Maximum VOC and Carbonyl Levels Compared to Acute Health Benchmarks (ppb)

CHEMICAL NAME	24-hr Max Conc.	3-hr Max Conc.	Acute Benchmark	Ratio 24-hr Max/Acute Benchmark	Ratio 3-hr Max/Acute Benchmark
formaldehyde	6.37		40 ^a	1.59E-01	
benzene	1.07	0.59	9 ^a	1.19E-01	6.55E-02
toluene	2.27	3.88	1000 ^a	2.27E-03	3.88E-03
chloroform	0.22	0.09	100 ^a	2.17E-03	9.12E-04
tetrachloroethylene	0.32	0.20	200 ^a	1.58E-03	9.78E-04
chloromethane	0.71	0.60	500 ^a	1.41E-03	1.20E-03
methyl-t-butyl-ether	1.65	0.18	2000 ^a	8.27E-04	8.98E-05
xylene	1.45	1.20	2000 ^a	7.24E-04	5.99E-04
dichloromethane	0.42	0.57	600 ^a	6.97E-04	9.54E-04
trichloroethylene	1.14	0.65	2000 ^a	5.72E-04	3.26E-04
methyl ethyl ketone	2.03	1.29	4000 ^b	5.08E-04	3.23E-04
carbon tetrachloride	0.12	0.09	300 ^b	4.07E-04	2.91E-04
1,3-butadiene	0.19	0.14	1000 ^c	1.87E-04	1.44E-04
carbon disulfide	0.17	0.07	1000 ^d	1.67E-04	6.95E-05
acetone	3.61		26000 ^a	1.39E-04	
acrylonitrile	0.01	ND (<0.048)	100 ^a	1.17E-04	<4.80E-04
1,1,1-trichloroethane	0.17	0.06	2000 ^a	8.59E-05	2.97E-05
acetaldehyde	2.01		25000 ^e	8.03E-05	
styrene	0.23	0.21	5000 ^b	4.67E-05	4.25E-05
p-dichlorobenzene	0.03	0.07	2000 ^a	1.67E-05	3.49E-05
n-hexane	0.68	0.73	50000 ^d	1.35E-05	1.45E-05
1,2-dichloroethane	0.01	0.01	1000 ^d	1.18E-05	6.58E-06
ethylbenzene	0.44	0.36	100000 ^d	4.45E-06	3.63E-06
chlorobenzene	0.04	0.01	10000 ^e	3.52E-06	8.19E-07
1,1-dichloroethene	0.01	ND (<0.019)	5000 ^e	1.46E-06	<3.80E-06
isopropylbenzene	0.03	0.02	50000 ^e	6.60E-07	4.07E-07
cyclohexane	0.15	0.21	300000 ^d	4.88E-07	7.07E-07
1,2-dichloropropane	ND (<0.014)	ND (<0.014)	50 ^a	<2.80E-04	<2.80E-04
vinyl chloride	ND (<0.016)	ND (<0.016)	500 ^a	<3.20E-05	<3.20E-05
1,1-dichloroethane	ND (<0.018)	0.02	100000 ^d	<1.80E-07	1.72E-07
1,2-dibromoethane	ND (<0.015)	ND (<0.015)	45 ^d	<3.33E-04	<3.33E-04

a = acute ATSDR MRL b=acute CAL REL c=OSHA PEL d=NIOSH REL e=ACGIH TLV ND = not detected

To eliminate seasonality bias, the mean VOC and carbonyl data presented below are for the one-year period with the largest number of valid samples. For VOC, that time period was 9 June 2005 – 4 June 2006; 56-59 valid samples per site were collected during that period. For carbonyls, the time period with the greatest number of samples was 1 September 2005 – 27 August 2006. At the Draper site, 34 valid formaldehyde and acetone samples and 30 valid acetaldehyde samples and, at the other Warwick sites, 58-59 valid formaldehyde and acetone samples and 54-56 valid acetaldehyde samples were collected during that period.

Table 3 lists the highest mean Warwick concentration and the site where that level occurred for each of the substances for which a non-cancer chronic effects health benchmark was available. The mean concentration divided by the chronic non-cancer benchmark is also shown. The chronic non-cancer benchmark is exceeded if that ratio is greater than 1.0.

Average (arithmetic mean) concentrations of all of the VOC and carbonyls measured were substantially lower than the corresponding chronic non-cancer health benchmarks. The substances with levels closest to the chronic non-cancer benchmarks were formaldehyde, acetaldehyde and benzene; the highest mean measured concentration of those substances in Warwick were 33%, 17% and 9%, respectively of the corresponding chronic non-cancer

Table 3 Mean VOC & Carbonyl Levels Compared to Chronic Non-Cancer Benchmarks (ppb)

CHEMICAL NAME	Highest Mean Warwick Concentration	Site with Highest Mean	Chronic Non-cancer Benchmark	Highest Mean Conc./Chronic Benchmark
formaldehyde	2.67	Field View	8 ^a	3.33E-01
acetaldehyde	0.84	Field View & Draper	5 ^b	1.68E-01
benzene	0.27	Field View	3 ^a	8.98E-02
1,3-butadiene	0.04	Field View	0.9 ^b	4.28E-02
xylenes	0.34	Field View	20 ^b	1.69E-02
chloromethane	0.49	Smith	40 ^b	1.23E-02
toluene	0.62	Field View	80 ^a	7.81E-03
carbon tetrachloride	0.08	Smith	30 ^a	2.79E-03
chloroform	0.03	Field View	20 ^a	1.41E-03
tetrachloroethylene	0.06	Lydick	40 ^a	1.40E-03
n-hexane	0.17	Field View	200 ^b	8.26E-04
trichloroethylene	0.07	Fire Station	100 ^a	6.88E-04
methyl-t-butyl-ether	0.39	Field View	700 ^a	5.58E-04
ethylbenzene	0.10	Field View	200 ^b	5.10E-04
2,2,4-trimethylpentane	0.08	Field View	200 ^c	4.16E-04
dichloromethane	0.11	Fire Station	300 ^a	3.81E-04
methyl ethyl ketone	0.55	Fire Station	1700 ^b	3.23E-04
styrene	0.02	Field View	60 ^a	3.20E-04
isopropylbenzene	0.01	Field View	80 ^b	1.75E-04
carbon disulfide	0.03	Draper	200 ^b	1.73E-04
acetone	1.36	Fire Station	13000 ^a	1.05E-04
1,1,1-trichloroethane	0.02	Fire Station	700 ^d	2.54E-05
cyclohexane	0.04	Fire Station	1700 ^b	2.11E-05

a = chronic ATSDR MRL b=EPA RfC c=NY DEC d=intermediate ATSDR MRL

benchmarks. The chronic benchmark for formaldehyde is the ATSDR chronic MRL, which is based on respiratory effects, the benchmark for acetaldehyde is the US EPA RfC, which is based on degeneration of the olfactory epithelium and the benchmark for benzene is the ATSDR chronic MRL and is based on immunological effects.

For the Warwick sites, the mean concentrations of the substances associated with fuel use and fuel burning tended to be highest at the Field View site, while the mean concentration for industrial and commercial solvents were highest at the Fire Station and Lydick sites.

Concentrations of six of the VOC and carbonyls were above the corresponding cancer health benchmarks, which correspond to a lifetime risk of one in one million, at all of the Warwick sites. A seventh substance exceeded the cancer benchmark at two of the Warwick sites. Concentrations of two additional VOC carcinogens were elevated at one of the Warwick sites and were close enough to the health benchmark and similar enough in action to other substances with elevated levels to warrant further investigation.

The highest mean concentration of the carcinogens measured at the Warwick sites, along with the cancer benchmark and the ratio of the concentration to the benchmark, are listed in Table 4. Note that a ratio higher than 1.0 indicates that the risk from that pollutant was greater than the one in one million (10^{-6}) risk levels.

Table 4 Mean VOC and Carbonyl Levels Compared to Cancer Benchmarks (ppb)

CHEMICAL NAME	Highest Mean Concentration	Site with Highest Mean	Cancer benchmark	Highest mean/cancer benchmark
formaldehyde	2.67	Field View	0.06 ^a	44.5
carbon tetrachloride	0.08	Smith	0.01 ^a	8.4
benzene	0.27	Field View	0.04 ^a	6.7
chloroform	0.03	Field View	0.008 ^a	3.5
acetaldehyde	0.84	Draper	0.3 ^a	2.8
1,3-butadiene	0.04	Field View	0.015 ^a	2.6
tetrachloroethylene	0.06	Lydick	0.025 ^b	2.2
trichloroethylene	0.07	Fire Station	0.09 ^b	0.8
dichloromethane	0.11	Fire Station	0.6 ^a	0.2

a = 10^{-6} risk level based on EPA IRIS cancer potency factor

b = 10^{-6} risk level based on California cancer potency factor

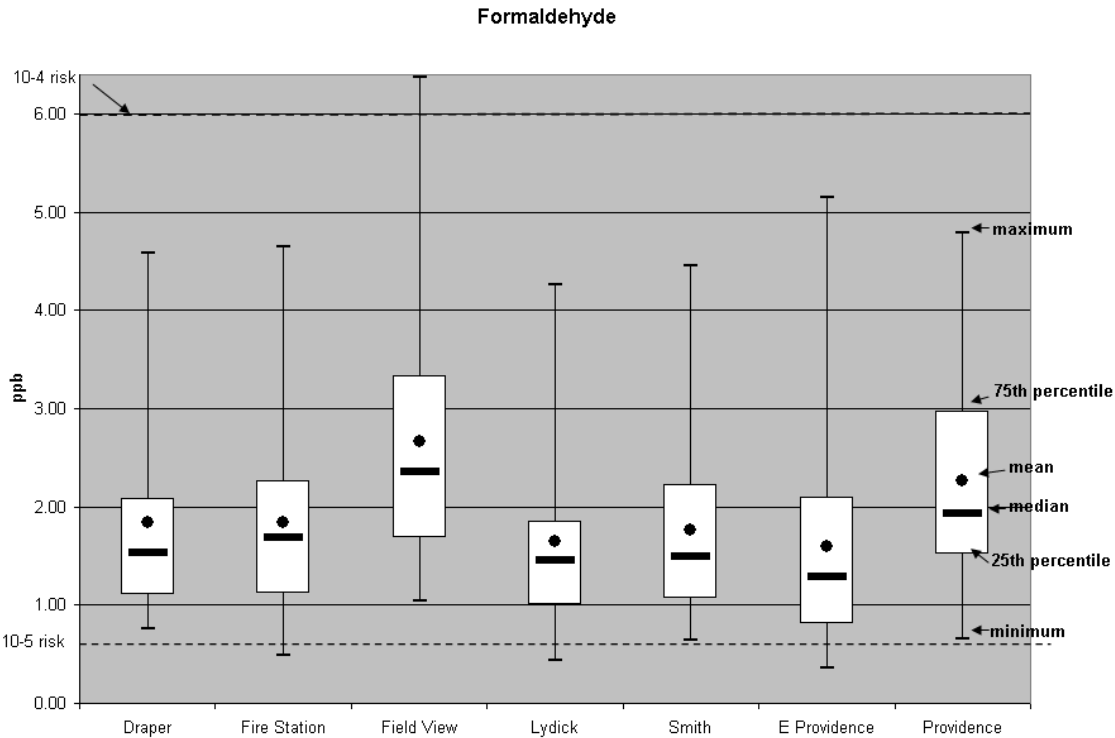
Further discussion of the pollutants listed in Table 4 follows.

9.1.1 Formaldehyde and Acetaldehyde

Formaldehyde levels at the Warwick sites were 30 to 40 times higher than the one in one million risk level benchmark, by far the highest level of cancer risk of any of the pollutants measured at those sites. Note that the US EPA is in the process of reevaluating the formaldehyde cancer potency estimate in its IRIS database, on which this risk benchmark is based. The California cancer potency for formaldehyde is approximately half the IRIS value; therefore, using the California potency would reduce the risk level by half, but formaldehyde would still be the highest risk pollutant measured at the Warwick sites.

Formaldehyde levels at the five Warwick sites and the comparison sites in East Providence and Providence are shown in Figure III. As can be seen in that figure, both the mean and median concentrations at the Field View site were substantially higher than at the other Warwick and the comparison sites. That difference is highly statistically significant with the paired sample t-test.

Figure III Formaldehyde Levels at Warwick and Comparison Sites



Formaldehyde sources are often difficult to pinpoint because, in addition to being emitted directly from combustion and other sources, formaldehyde is formed in the atmosphere by secondary photochemical reactions of other pollutants. Because photochemical reactions require heat and light, secondary formation occurs to a larger extent in the summer than in the cooler seasons.

Figure IV shows daily formaldehyde concentrations at the Field View and Fire Station sites throughout the study period. During the cooler months (November through March), the formaldehyde concentrations at the two sites were similar, but, during both the summer of 2005 and the summer of 2006, formaldehyde concentrations on most days were higher at Field View than at the Fire Station. This relationship can also be seen in Figure V, which shows the relationship between formaldehyde concentrations at each site and the maximum outdoor temperature on the sampling day. On days when the highest temperature was less than 50°F, formaldehyde levels at Field View were similar to those at the other sites. However, when temperatures were above 60°F, the Field View formaldehyde levels were approximately 1 ppb higher than at the other sites. Note that the difference in concentrations, by itself, corresponds to a risk level more than ten times higher than the cancer health benchmark.

Figure IV Daily Formaldehyde Levels at Field View and Lydick Sites

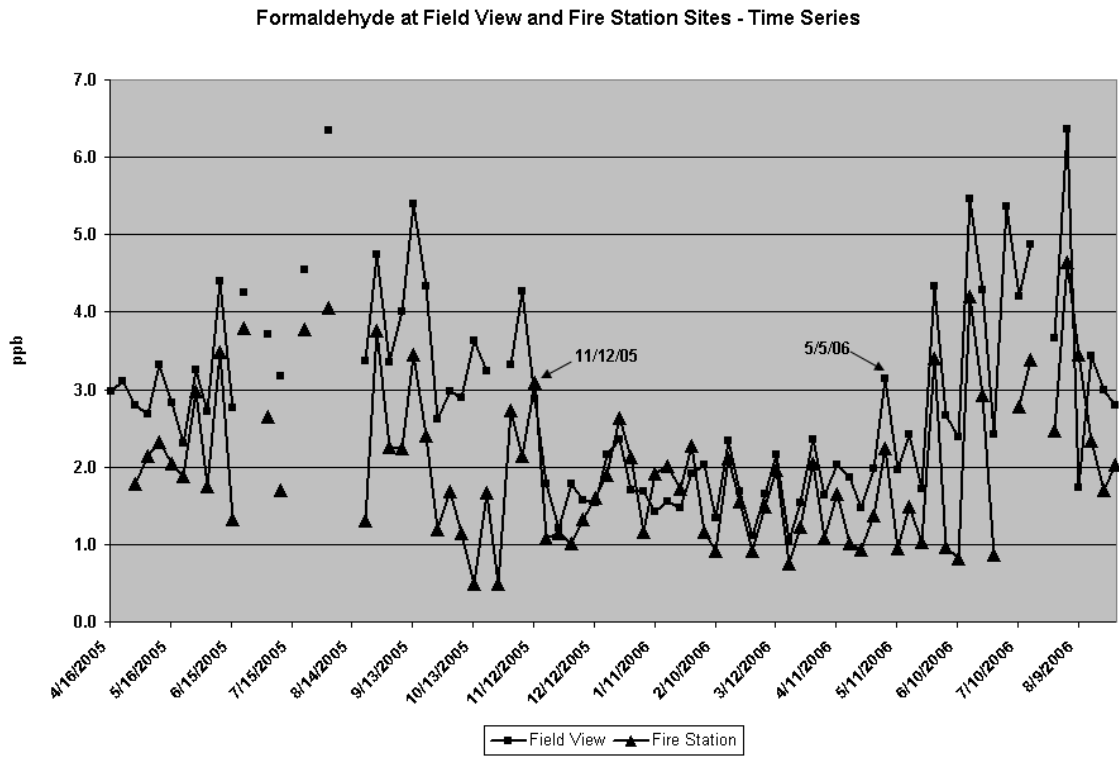
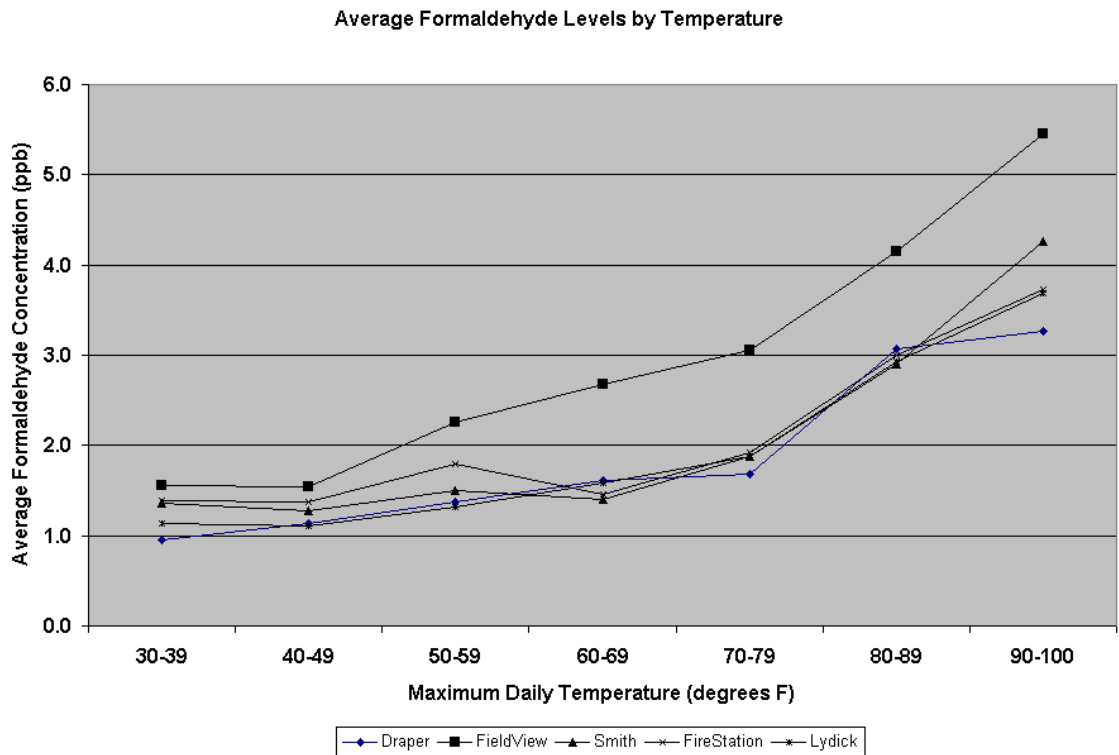


Figure V Relationship between Formaldehyde Levels and Ambient Temperature



A discrepancy between pollutant levels at sites could be caused by a bias in the sampling equipment. If, for instance, the carbonyl sampling unit at the Field View site were improperly calibrated and pulled more air through the traps than the samplers at the other sites, measured concentrations at that site would be higher.

However, if the elevated Field View formaldehyde levels were caused by sampler bias, levels of acetaldehyde and acetone, which were measured using the same equipment, would also have been higher at that site than at the other sites. This was not the case, as is shown in Figures VI and VII. The concentration of acetaldehyde at Field View was not statistically different from those at the Fire Station and Draper and was lower than at the comparison sites. The concentration of acetone at Field View was statistically equivalent to that at the Fire Station, Smith and E. Providence sites and less than that at the Providence site. Since the concentrations of these substances were not elevated at the Field View site relative to the other sites, it is unlikely that a sampling error caused the elevated formaldehyde readings at that site.

Note that ozone in the atmosphere can also interfere with the accurate formaldehyde measurements. However, since ozone scrubbers were installed on all of the carbonyl monitors at the beginning of the study and were replaced at all of the sites in early 2006, it is unlikely that atmospheric ozone was responsible for the elevated formaldehyde levels recorded at the Field View site.

Figure VI Acetaldehyde Levels at Warwick and Comparison Sites

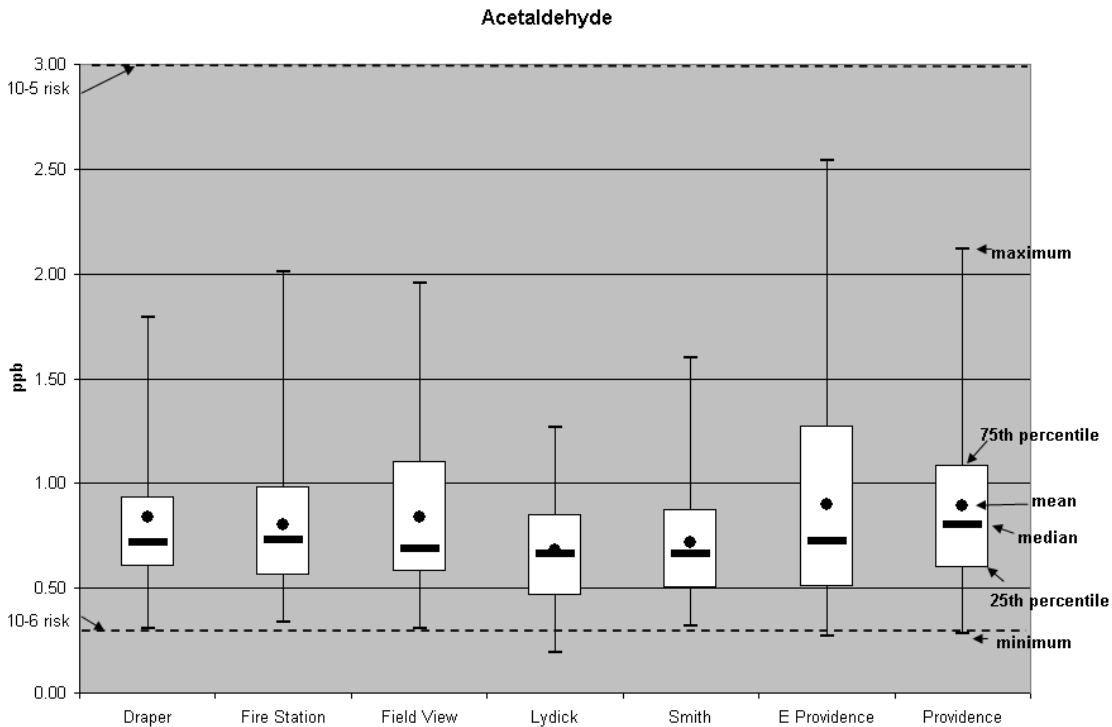
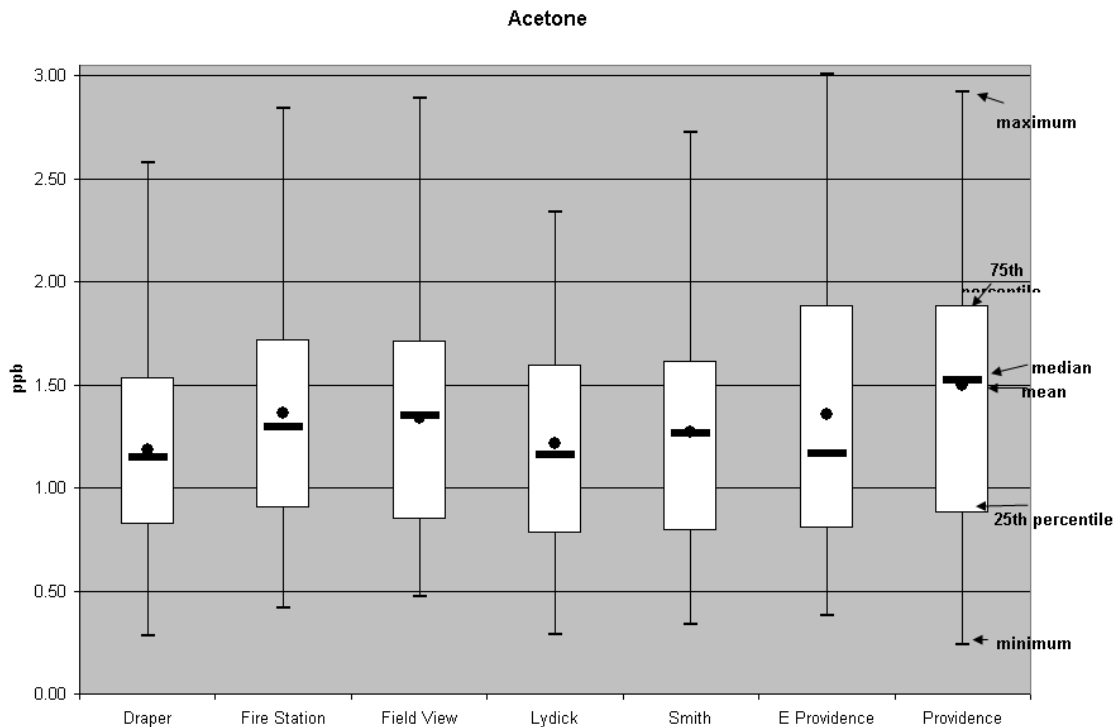


Figure VII Acetone Levels at Warwick and Comparison Sites



Note also that, although measured acetaldehyde levels were not disproportionately elevated at the Field View site, acetaldehyde is of concern because levels at all sites were above the cancer health benchmark. Levels of acetone, which is not a carcinogen, were considerably lower than the health benchmarks and are, therefore, not of concern.

Since the elevated Field View formaldehyde levels do not appear to be associated with sampler errors, it is likely that these elevations were due to emissions of formaldehyde or formaldehyde precursor pollutants. The source of these emissions could be an off-site formaldehyde-emitting source, like aircraft, off-site sources that emit pollutants that are converted in the atmosphere to formaldehyde, or a localized source, such as off-gassing from building materials in nearby structures.

To try to determine whether an off-site emissions source, like the airport, was associated with the elevated formaldehyde levels observed at Field View, RI DEM looked for an association between wind direction and formaldehyde concentrations. This analysis was hampered by the fact that the carbonyl samples were collected over 24-hour periods and, since the wind direction varies during the course of most days, it is not possible to directly correlate the concentrations with specific wind directions.

In an attempt to elucidate a relationship between wind direction and formaldehyde connections, RI DEM conducted the following analyses:

- The difference between and ratio of the formaldehyde concentrations at the Field View and Lydick sites were calculated for each day that measurements were available for both sites. The wind direction patterns on days when those differences and ratios were highest and lowest were compared. On the day when both the difference and ratio between Field View and Lydick formaldehyde levels was highest, 15 October 2005, the winds were from the northeast the entire day. This is consistent with an airport influence. However, no pattern was evident for the other days with high or low difference or ratios of these values. Therefore, this analysis was inconclusive.
- Days when there was a persistent wind in each direction were identified and matched with the formaldehyde concentrations at the sites on those days. No relationship between persistent wind direction and relative formaldehyde concentrations at the sites was detected.
- Average concentrations by wind direction were calculated by weighting formaldehyde concentrations measured at each site on each sampling day by the number of hours of that day that the wind was from each direction. The results of this analysis are shown in Figure VIII. Field View formaldehyde was higher than at the other sites regardless of wind direction.
- To investigate the possibility that wind directions at certain times of the day have a dominant influence on formaldehyde concentrations, days were divided into four time periods and the above analyses was repeated for each of these periods. Again, elevated Field View concentrations could not be linked with wind direction.

The fact that we were unable to find a link between wind direction and elevated levels of formaldehyde at Field View does not rule out the possibility that an off-site source, like the airport, is a major contributor to these concentrations. Any attempt to link 24-hour average results with specific wind directions is limited at best. It does appear that, since the difference between the formaldehyde concentrations at Field View and those at the other sites tended to be substantially higher when the temperatures were above 60°F, secondary formation from off-site emissions of other pollutants may be an important contributor to the Field View levels.

As discussed above, one or more on-site sources may have also contributed to the elevated Field View formaldehyde levels. At the time of the study, the Field View monitor was located in the yard of an occupied residence. Several sheds and a swimming pool were located in the yard and landscaping equipment was sometimes operated on the property. Since the study ended, RIAC has purchased that property and most of the neighboring properties and the structures on those properties have been removed. Figure IX shows before and after pictures of that site.

The removal of the structures and activities on this site provides an opportunity to investigate whether localized sources contributed to the elevated formaldehyde levels formerly seen at this site. If additional sampling shows that Field View formaldehyde levels continue to be elevated relative to the other sites, a more comprehensive attempt at identifying off-site sources is indicated.

Figure VIII Relationship of Formaldehyde Levels to Wind Direction

Average Formaldehyde Weighted by Hourly Wind Direction

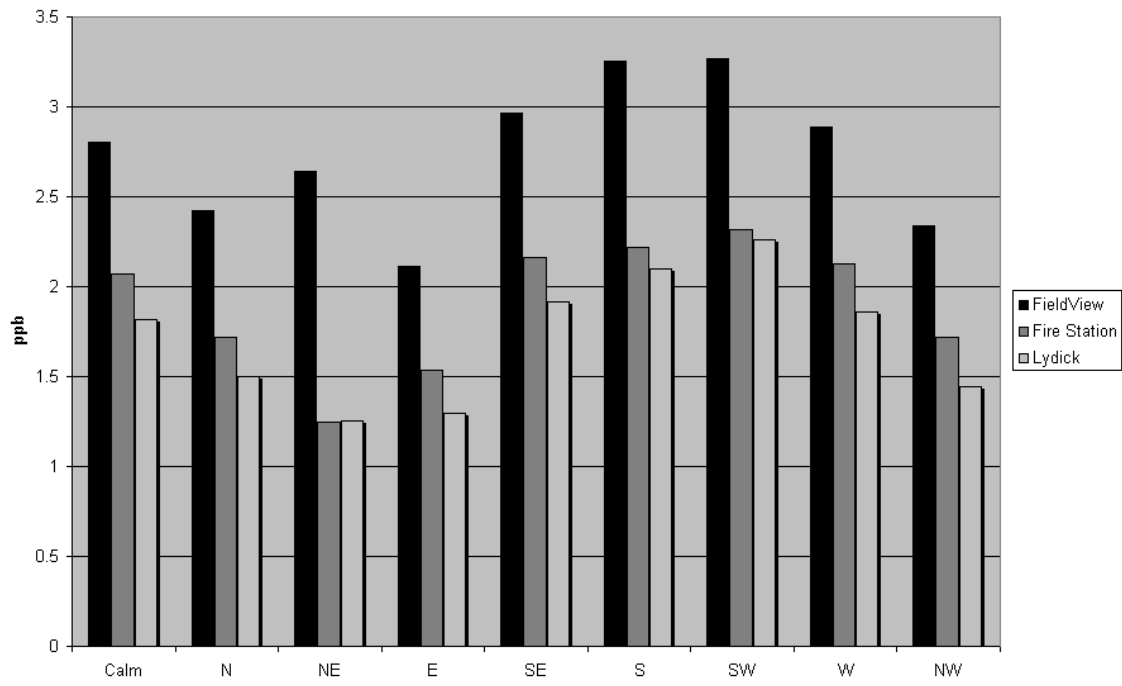
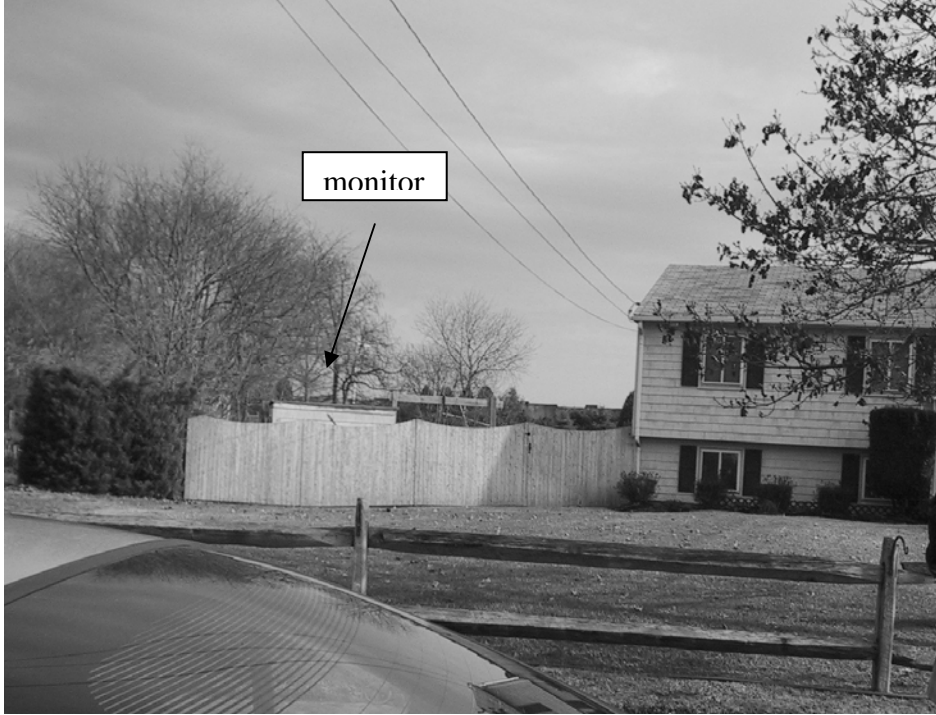


Figure IX Field View Site During the Study Period and After Purchase by RIAC



Field View site during the study period.



Field View site after purchase by RIAC

9.1.2 Benzene, 1,3-Butadiene and Other Mobile Source Pollutants

As discussed above, the average concentrations of benzene and 1,3-butadiene measured at the Warwick and comparison sites exceeded the cancer health benchmark, which corresponds to a lifetime cancer risk of one in one million (10^{-6}). In addition, the maximum daily level of benzene was closer to the acute and chronic non-cancer health benchmarks than any of the other VOC measured.

Figures X and XI show the concentrations of benzene and 1,3-butadiene measured at the Warwick and comparison sites between 9 June 2005 and 4 June 2006. The mean concentrations of benzene at the Warwick sites (0.21 – 0.27 ppb) were similar to that in E. Providence (0.24 ppb), higher than that at the W. Greenwich rural site (0.13 ppb) and lower than those at the urban Providence and highway dominated Pawtucket sites (0.36 and 0.44 ppb, respectively). The risks associated with the benzene levels at the Warwick sites were 5 – 7 times the 10^{-6} cancer risk health benchmark. The mean concentration at Field View site was slightly higher than at the other Warwick sites; that difference was statistically significant at the $p < 0.05$ level using a two-tailed paired sample t-test. Using the same test, the concentration of benzene was significantly lower at the Draper site, the Warwick site most distant from the airport, than at the other Warwick sites.

The mean concentrations of 1,3-butadiene at the Warwick sites near the airport, (0.037 – 0.039 ppb), were similar to the mean concentration at the E. Providence site (0.037 ppb), higher than at the W. Greenwich rural site and the Draper distant Warwick site (0.013 and 0.028 ppb, respectively) and lower than those at the Providence urban and Pawtucket highway sites (0.063 and 0.095 ppb, respectively). The risks associated with the benzene levels at the Warwick sites were 2 - 3 times the 10^{-6} cancer risk health benchmark. The 1,3-butadiene concentration at the Draper site was significantly lower than at the other Warwick sites, using the two-tailed paired sample t test.

Other mobile vehicle related pollutants followed a similar pattern – levels at the Warwick sites tended to be approximately equal to those at the E. Providence site, lower than those at the Pawtucket and Providence sites, and higher than those in W. Greenwich. As with benzene, mean concentrations of the other mobile source pollutants were lower at the Draper site than at the sites closer to the airport. Since those sites are also close to major roadways and the mobile source constituents measured are, in general, present in gasoline as well as in aircraft fuels, it is not possible to link these elevated concentrations directly with airport operations. Wind direction data did not yield additional information about the contribution of specific sources to these levels.

Figure X Benzene Levels at Warwick and Comparison Sites

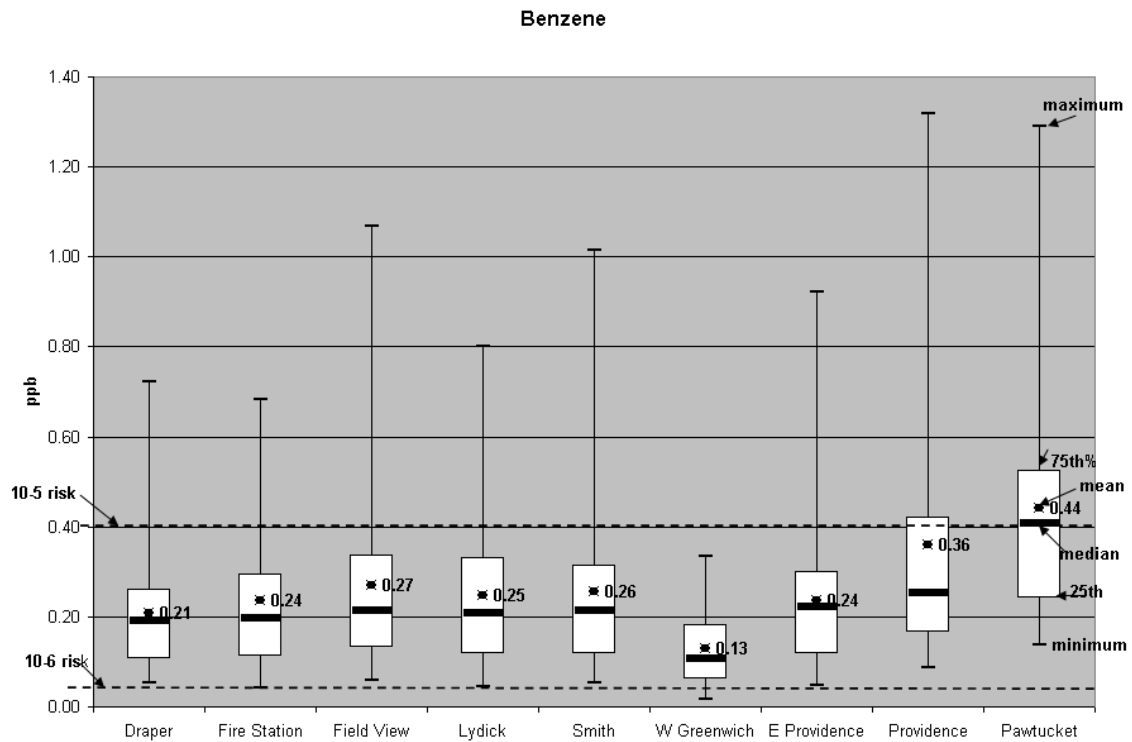
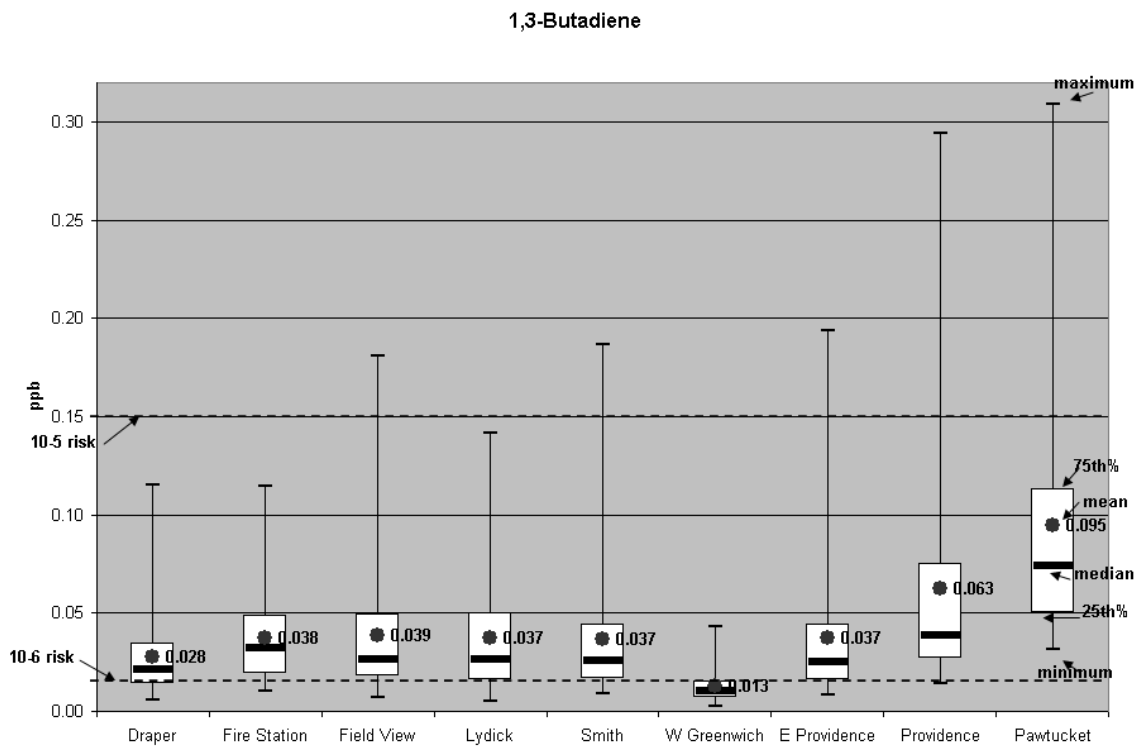


Figure XI 1,3-Butadiene Levels at Warwick and Comparison Sites



It is interesting to note that, while the levels of benzene and some of the other mobile source pollutants levels were slightly higher at the Field View site than at the other Warwick sites, the benzene concentrations at all of the Warwick sites were highly correlated with each other ($r^2 = 0.89 - 0.98$). For other mobile source pollutants, however, concentrations were highly correlated at the Fire Station, Lydick, Smith, and to a lesser extent, the Draper sites, but showed little or no correlation with levels at the Field View site. This may indicate that the levels of mobile source-related VOC at the Field View site were influenced by a source or sources that did not strongly influence the other sites. It is not clear whether that source was a localized, on-property source, or an off-property source like the airport.

9.1.3 Chloroform and Carbon Tetrachloride

As discussed above, the average concentrations of chloroform and carbon tetrachloride measured at the Warwick and comparison sites also exceeded the 10^{-6} cancer health benchmark. Levels of carbon tetrachloride were similar across the State (mean 0.079 – 0.084 ppb), approximately eight times the 10^{-6} cancer risk health benchmark. Carbon tetrachloride is no longer produced or used, but is persistent in the atmosphere. Carbon tetrachloride levels are shown in Figure XII

Chloroform levels at all of the Warwick and comparison sites corresponded to a cancer risk two to three times above the 10^{-6} cancer benchmark. As shown in Figure XIII, the mean at Field View was slightly higher than at the other sites, but this difference was not statistically significant. The concentration at the W. Greenwich site was slightly lower than at the other comparison sites and the Warwick sites; this difference was significant using the paired sample t test. This is consistent with the fact that chloroform is largely a background pollutant but that anthropogenic activity, largely related to off-gassing from chlorinated water, contributes to atmospheric concentrations of that pollutant.

Note that elevated levels of chloroform were seen at all of the sites near the airport on Thursday, 16 February 2006; levels were particularly elevated at the Field View and Smith sites on that date. The wind was largely calm during the morning hours of that day and from the south in the afternoon. The source of the elevated levels on that day could not be identified. A time series graph showing chloroform levels over the course of the study is included as Figure XIV.

Figure XII Carbon Tetrachloride Levels at Warwick and Comparison Sites

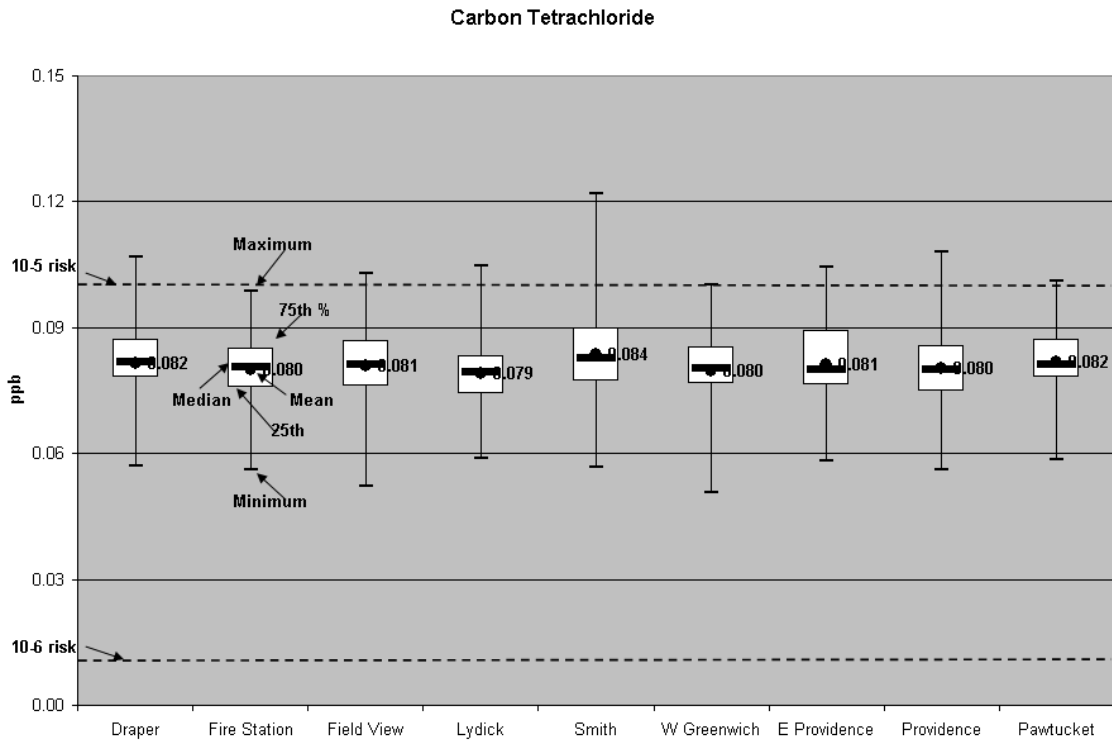


Figure XIII Chloroform Levels at Warwick and Comparison Sites

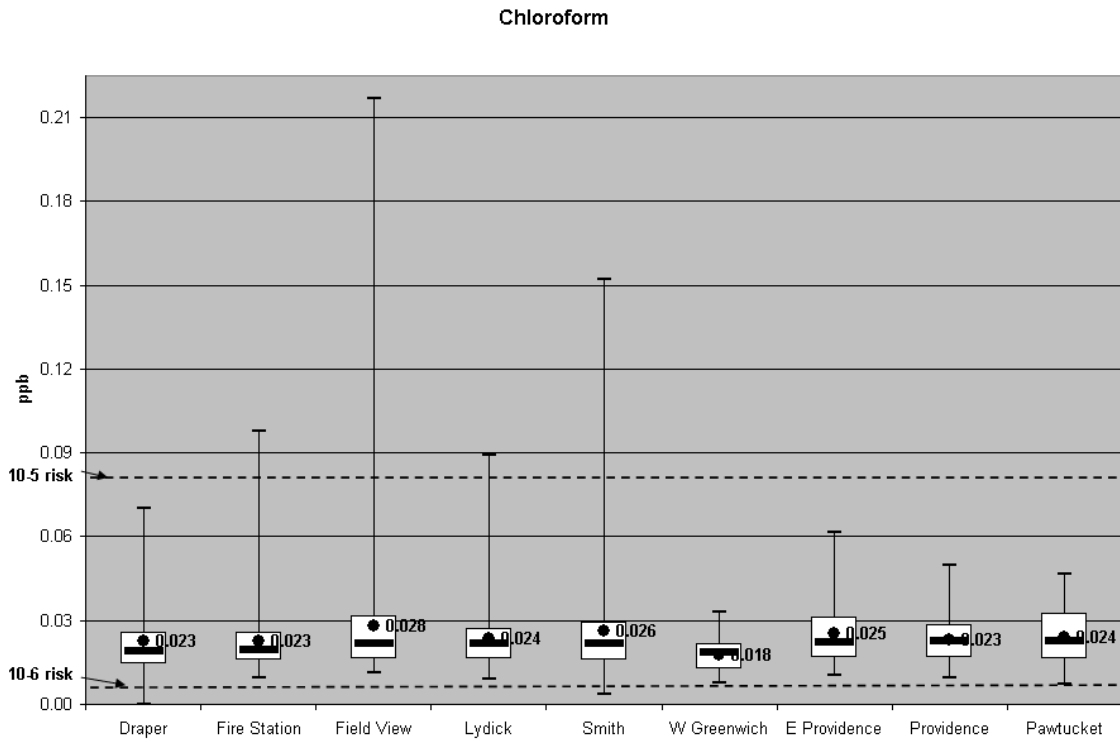
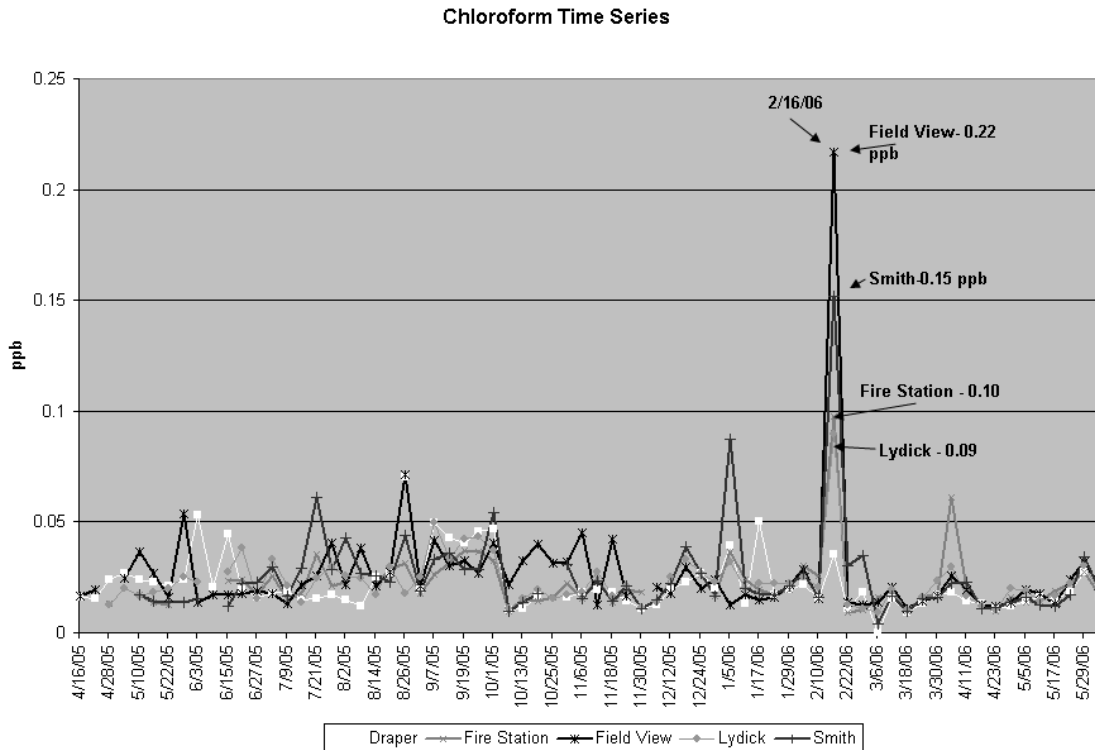


Figure XIV Daily Chloroform Levels at Warwick Sites



9.1.4 Chlorinated Solvents

Average levels of the chlorinated solvent tetrachloroethylene, also known as perchloroethylene, were above the 10^{-6} cancer risk benchmark at the Lydick and Fire Station sites as well as at the urban comparison sites. The mean concentration of that pollutant at the Lydick site, which was approximately twice the cancer benchmark, was higher than that at any of the other sites in the State.

Figure XV shows tetrachloroethylene levels at the Warwick and comparison sites. Note that a value of 0.0085 ppb, which is one-half the Minimum Detection Level (MDL) for that pollutant, was used for samples reported as not detected (ND). For each of the Warwick sites and the Providence and Pawtucket sites, no more than 10% of the samples were ND, so the use of $\frac{1}{2}$ of the MDL instead of zero for ND samples increased the mean only marginally (0 – 6%). However, since 37% of the samples at the W. Greenwich site were ND, the use of $\frac{1}{2}$ MDL increased the mean by 48%. The fraction of samples at each site that were ND and the percent increase in the mean concentration when $\frac{1}{2}$ MDL was used instead of zero for ND samples is shown in Table 5.

Figure XV Tetrachloroethylene Levels at Warwick and Comparison Sites

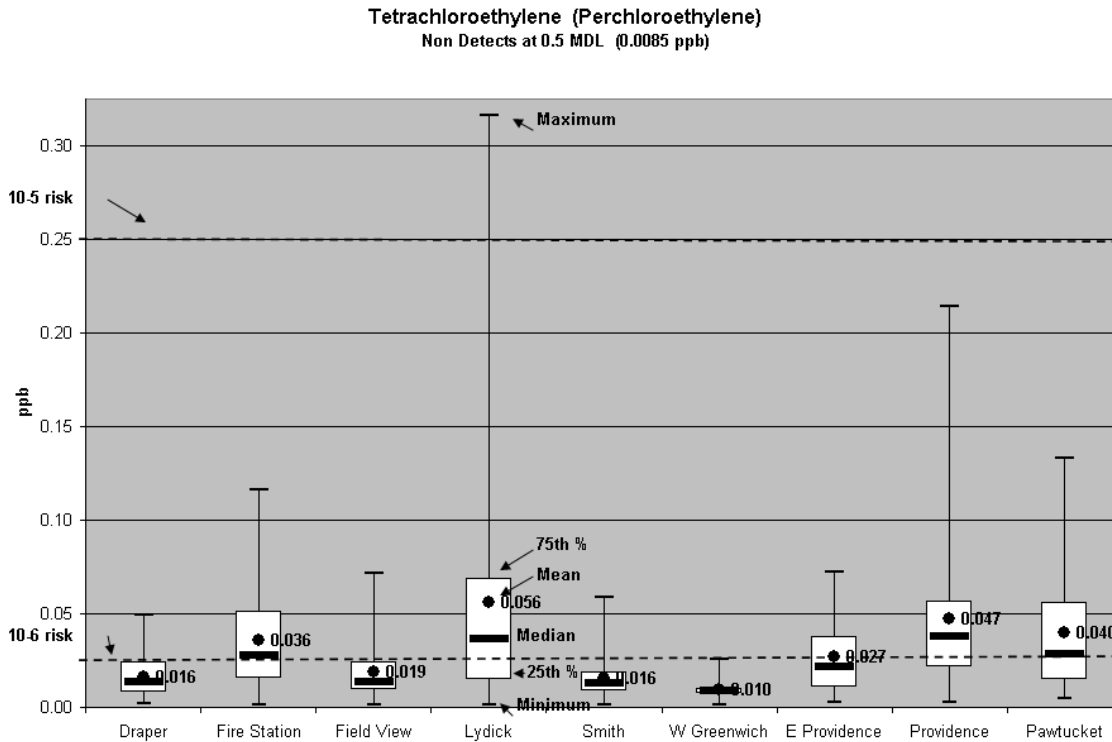


Table 5 Effect of Use of 1/2 MDL for Non Detect samples on Tetrachloroethylene Mean Levels

	Draper	Fire Station	Field View	Lydick	Smith	West Greenwich	East Providence	Providence	Pawtucket
Fraction ND	0.10	0.02	0.05	0.02	0.10	0.37	0.07	0.04	0.00
% Diff. in Mean	5%	<1%	2%	<1%	6%	48%	2%	4%	0%

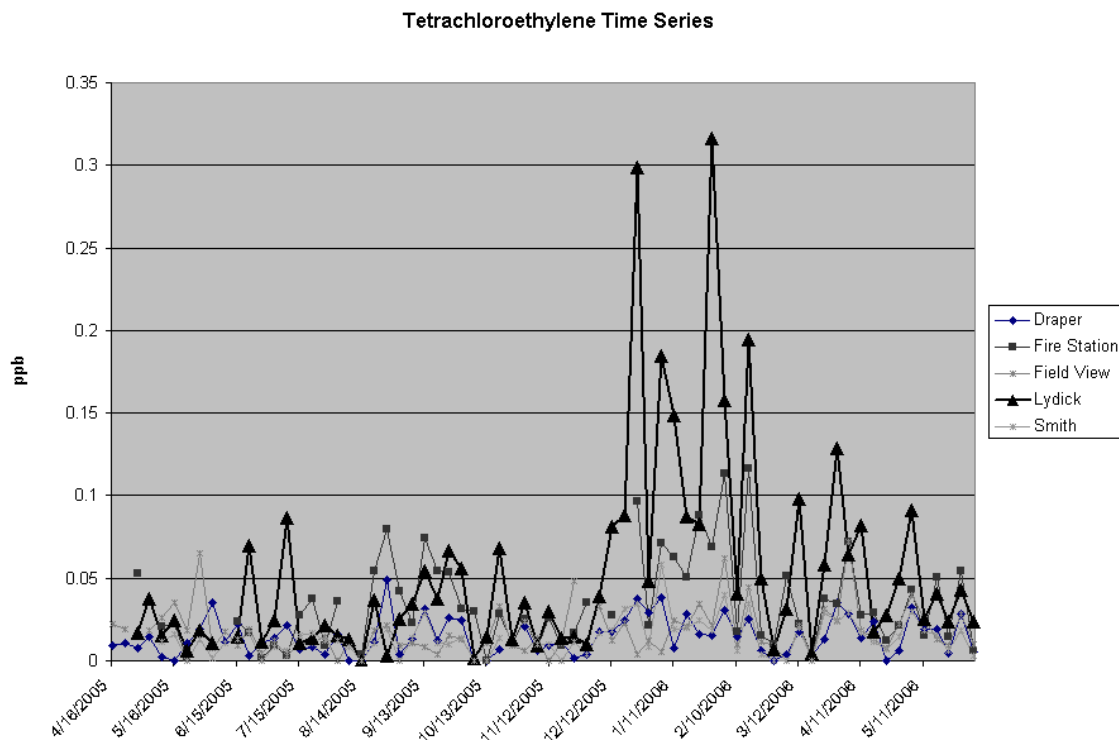
As can be seen in the time series graph shown below as Figure XVI, the tetrachloroethylene levels at the Lydick site and, to a lesser extent, at the Fire Station site, were considerably higher than the levels at the other sites on some days. This is very likely indicative of impacts from a commercial or industrial source or sources near those sites. As discussed above, it is difficult to identify sources impacting 24-hour samples due to the variability of wind direction during the sampling periods. However, an analysis correlating daytime wind directions with the days with the highest and lowest tetrachloroethylene levels at the Lydick and Fire Station suggested the following:

- Calm wind conditions were associated with higher tetrachloroethylene concentrations at both sites.

- Levels at Lydick tended to be higher when winds were from the northeast or west, suggesting that more than one source may be impacting this site. A dry cleaner that is located northeast of this monitor may be one of the impacting sources.
- Levels at the Fire Station appeared to be high more often when winds were from the southeast.
- At least one source that impacted the Lydick site operated on Sundays. On average, tetrachloroethylene levels were lowest on Sundays at all of the other Warwick sites and at the comparison sites, but the average Sunday level at Lydick was higher than on other days.

This information will be useful when RI DEM is able to conduct a field investigation to locate unknown sources of the pollutant and to better characterize emissions from known and newly identified sources in the area.

Figure XVI Daily Tetrachloroethylene Levels at Warwick Sites



As can be seen in Figures XVII and XVIII, mean concentrations of trichloroethylene and dichloromethane (methylene chloride) were higher at the Fire Station site than at the other Warwick sites and the comparison sites, including the urban sites. Although the mean concentrations of these pollutants did not exceed the levels corresponding to a 10^{-6} cancer risk level, they merited further investigation because chlorinated solvents have similar mechanisms of toxicity and therefore may act in a cumulative manner. Further, there is a residential neighborhood between the known sources of these pollutants and the Fire Station monitor; it is therefore likely that concentrations in that neighborhood are higher than those observed at the monitor.

As with tetrachloroethylene, trichloroethylene was not detected in all samples and, in conformance with US EPA conventions, ND values were recorded at 0.5 MDL (0.009 ppb). This did not make a large difference for the more urban sites, because a relatively small fraction of the samples at those sites were ND, but it did substantially increase the means calculated for the Smith, Draper and West Greenwich sites because of a high number of ND samples at those sites. The fraction of ND trichloroethylene samples and the percent increase in the mean when 0.5 MDL was used for the ND samples instead of zero is shown in the Table 6. This was not an issue for dichloromethane, because concentrations of that pollutant in virtually all of the samples were detectable.

Figure XVII Trichloroethylene Levels at Warwick and Comparison Sites

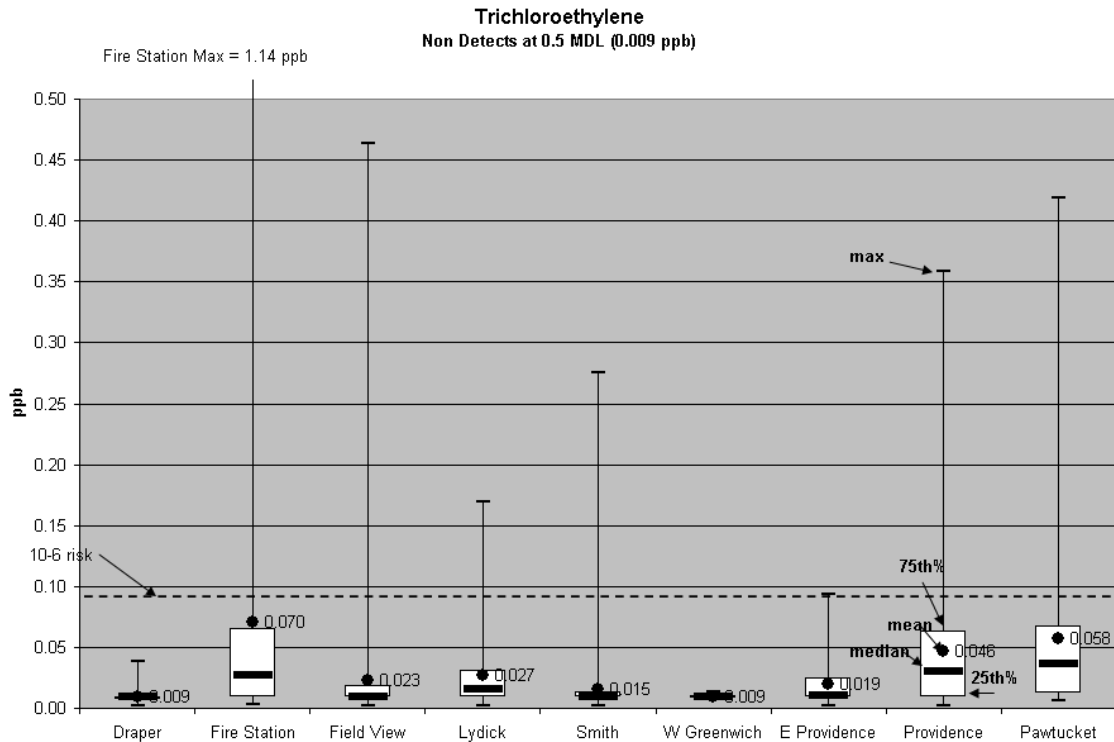
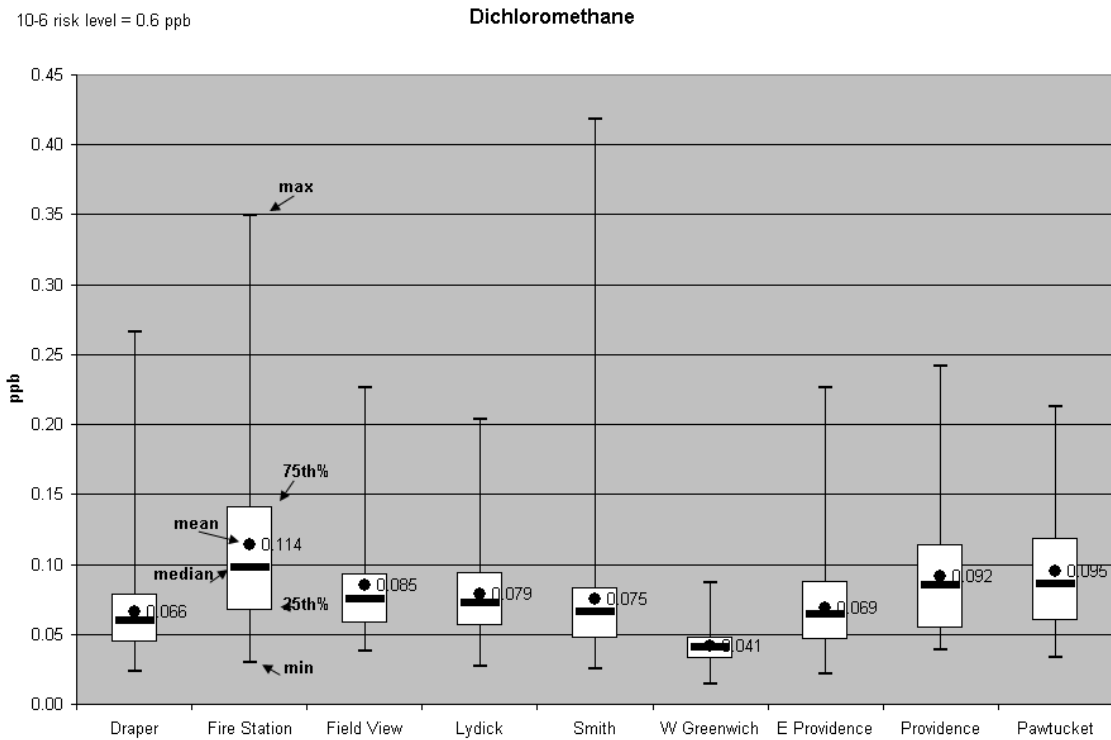


Table 6 Effect of Use of 1/2 MDL for Non Detect Samples on Trichloroethylene Mean Levels

	Draper	Fire Station	Field View	Lydick	Smith	West Greenwich	East Providence	Providence	Pawtucket
Fraction ND	0.51	0.18	0.28	0.24	0.41	0.92	0.28	0.19	0.10
% Diff. in Mean	95%	2%	12%	8%	31%	1000%*	14%	4%	2%

* Trichloroethylene was detected in only 5 of the 59 valid samples collected at the W. Greenwich site.

Figure XVIII Dichloromethane Levels at Warwick and Comparison Sites



Trichloroethylene levels were highest at the Fire Station site when the wind was calm or from the west. This is consistent with an impact from the industrial area near Jefferson Blvd.; several facilities which operate degreasers using that solvent have been identified in that area. The impacting source(s) apparently do not operate on Sundays, as the average trichloroethylene levels on Sundays were not elevated at the Fire Station relative to the other Warwick sites.

Dichloromethane levels were elevated at the Fire Station when the wind was calm and possibly also with northwest winds. As with trichloroethylene, levels were lower on Sundays, indicating that dichloromethane sources in that area probably do not operate on Sundays. Dichloromethane and trichloroethylene levels at the Fire Station did not correlate well, so there is no indication that the same source or sources cause the peaks of these two substances seen at that site.

As staff is available, RI DEM will follow up on this information to try to identify all sources that contribute to the elevated levels of chlorinated solvents and to determine whether those sources are operating in compliance with applicable regulations. Note that it does not appear that the airport is a source of chlorinated solvents.

9.2 Black Carbon and Fine Particulate Matter (PM2.5)

As discussed above, RI DEM operated aethalometers measuring black carbon (BC) at all five of the Warwick sites throughout the study period, May 2005 – August 2006. Co-located aethalometers were operated at the Smith site. Aethalometers were also operated throughout the sampling period at the Providence and E. Providence comparison sites. The aethalometers collect one-minute average concentration data but, since only hourly meteorological data were available, most of the analysis presented below is for one-hour average BC concentrations.

BC is an indicator of diesel/jet engine exhaust and has been shown elsewhere to correlate well with levels of ultrafine particulate matter and polycyclic aromatic hydrocarbons¹, but cannot be directly compared to a health benchmark. It is safe to say, however, that it is preferable for BC levels to be as low as possible.

The distributions of black carbon measurements at the Warwick and comparison sites for the 6,860 hours for which data were available for all sites are shown in Figure XIX. Mean and median BC concentrations were higher at the Fire Station than at the other Warwick sites; Fire Station BC levels were similar to those at the Providence urban comparison site.

Using paired sample t tests on all data available, the BC concentration at the Fire Station was significantly higher than at the other Warwick sites and the East Providence site but lower than in Providence. This finding is consistent with the large amount of traffic on roadways near the Fire Station site. The concentration at the Draper site was significantly lower than at all of the other Warwick sites and the comparison sites. The Lydick and Field View concentrations were not statistically different but were greater than that at Smith.

RI DEM performed additional analyses to determine which factors affected BC concentrations at the sites. Since the aethalometers produced data continuously over the study period, a large quantity of data was available, providing considerable statistical power.

9.2.1 BC and Wind Speed

As shown in Figure XX, BC carbon levels at all Warwick and comparison sites were highly dependent on wind speed. Average concentrations under calm wind conditions were approximately twice the concentrations during hours when the wind was 5 knots, three times those at 10 knots, four times those at 15 knots and up to 10 times those when the wind speed was 20 knots or more.

¹ Clean Air Task Force, “A Multi-City Investigation of the Effectiveness of Retrofit Emissions Controls in Reducing Exposures to Particulate Matter in School Buses,” January 2005.

Figure XIX Black Carbon Levels at Warwick and Comparison Sites

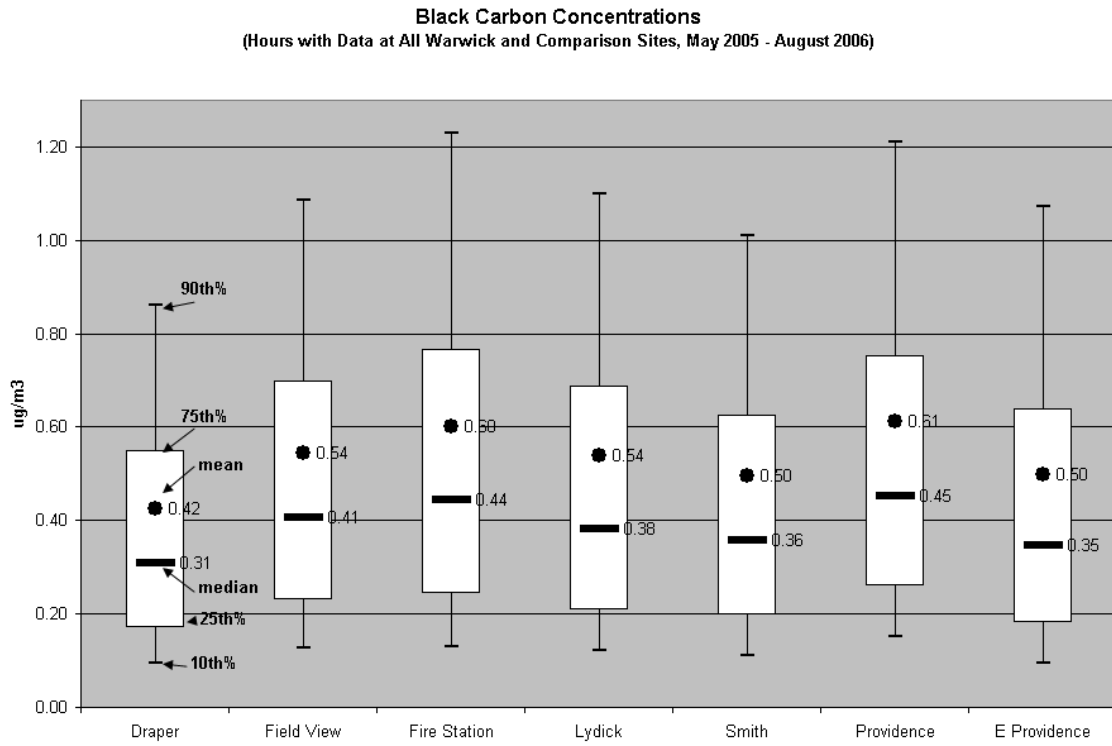
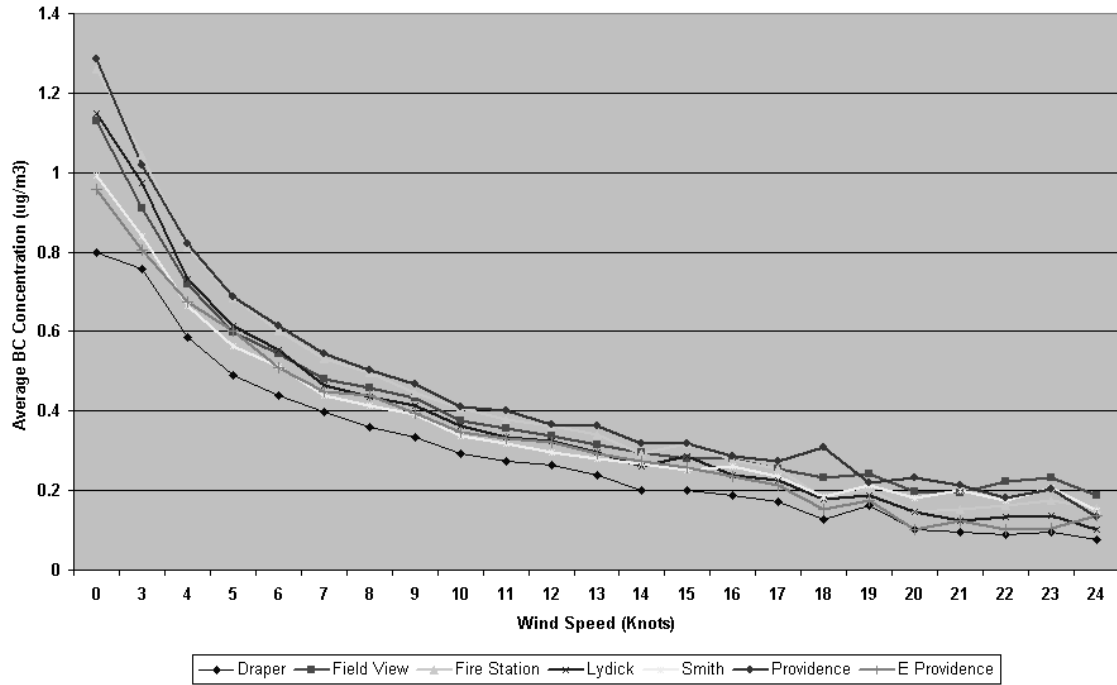


Figure XX Relationship between Black Carbon Levels and Wind Speed

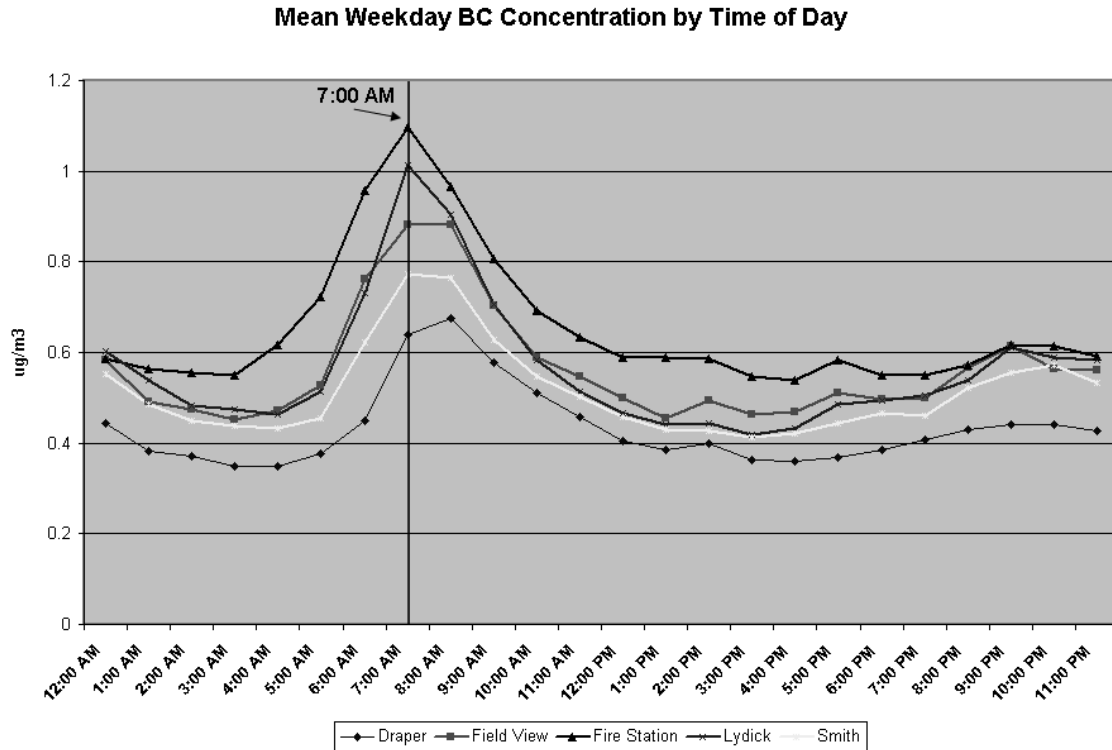
Mean Black Carbon Concentrations by Wind Speed



9.2.2 BC and Time of Day

As shown in Figure XXI, average BC levels on weekdays at all of the Warwick sites were lowest in the early morning hours, began to rise between 4:00 and 5:00 AM and peaked between 7:00 and 8:00 AM. Similar results were seen at the comparison sites.

Figure XXI Weekday Diurnal Variation in Black Carbon Levels



The morning peak is partly due to meteorology. The early morning hours tend to be associated with low ceiling heights and low wind speeds, which are in turn associated higher concentrations. Figure XXII shows average wind speed by time of day during the study period.

However, the time of day variation in BC concentrations is not just a function of wind speed. As is shown in Figure XXIII, average BC concentrations on weekend days, which have considerably less morning rush hour traffic, do not show the same pronounced 7:00 – 8:00 AM peak as is seen on weekdays. In addition, the average BC concentrations at the Fire Station, which are higher than at the other sites for most of the daytime hours on weekdays, are similar to those at Field View and Lydick on weekend days, when commercial traffic is less pronounced in that area. Therefore, both meteorology and motor vehicle activity patterns contribute to the diurnal BC patterns.

Figure XXII Average Wind Speed by Time of Day

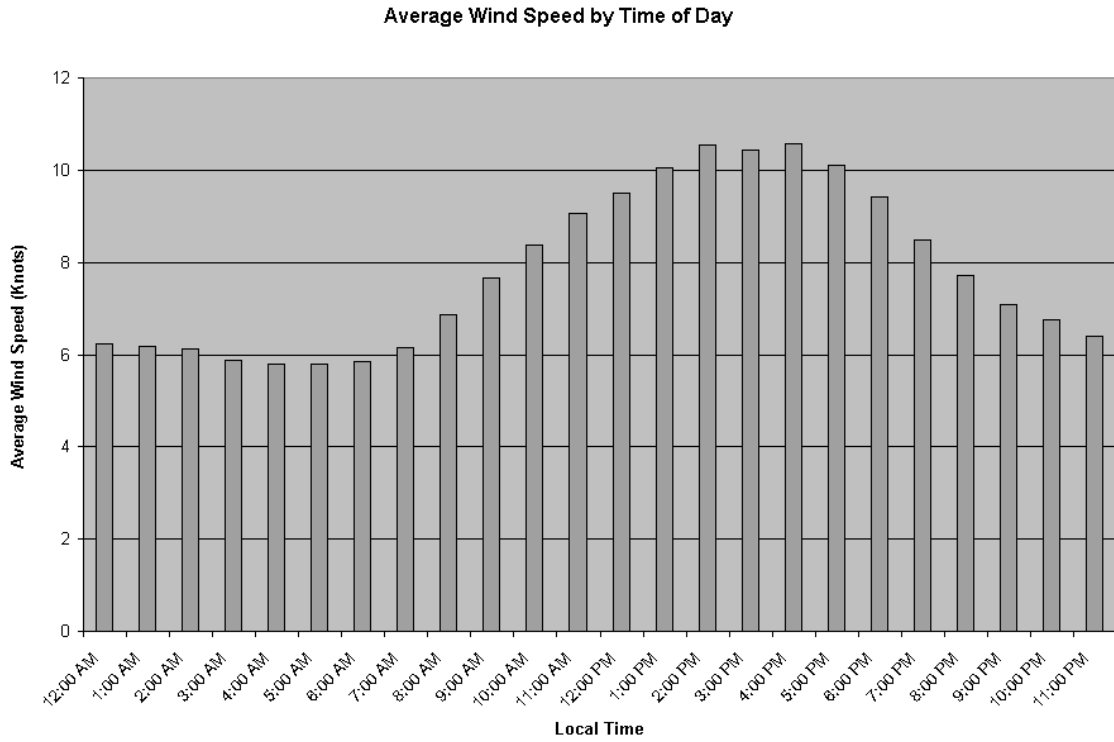
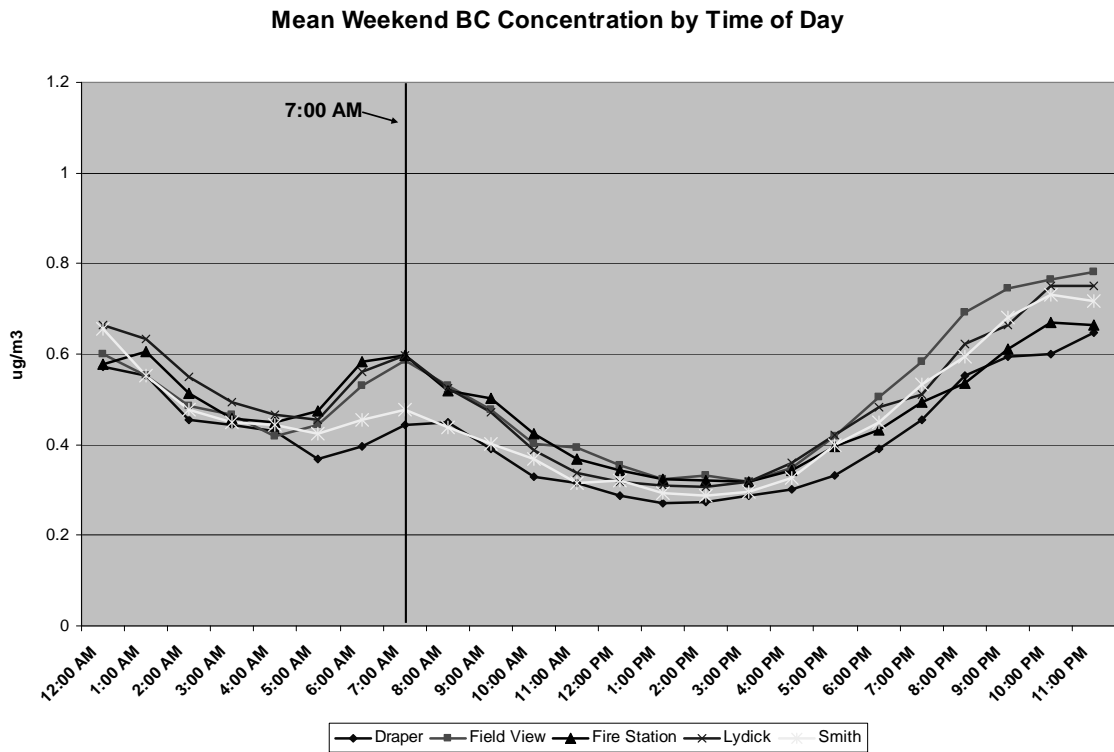


Figure XXIII Weekend Diurnal Variation in Black Carbon Levels



9.2.3 *BC and Wind Direction*

Wind direction also significantly influences BC levels in Warwick. This is important because linking BC levels to wind direction is essential for identifying the contribution of specific sources to ambient concentrations of that pollutant.

An analysis of BC data by wind direction shows that the airport was a significant contributor to BC levels measured at the four nearby sites. Specifically, when the wind direction was from the north or east, the BC levels at the Field View site were significantly higher than at all of the other Warwick sites. When the wind was from the northeast, Field View and Smith were approximately equal and were significantly higher than the other three Warwick sites. When the wind was from the southeast or south, the Fire Station was significantly higher than the other sites and when the wind was from the southwest, Lydick was significantly the highest. Those wind directions are displayed on the map of the sites in Figure XXIV. The distributions of BC concentrations at the sites by wind direction are displayed in Figures XXV – XXVIII.

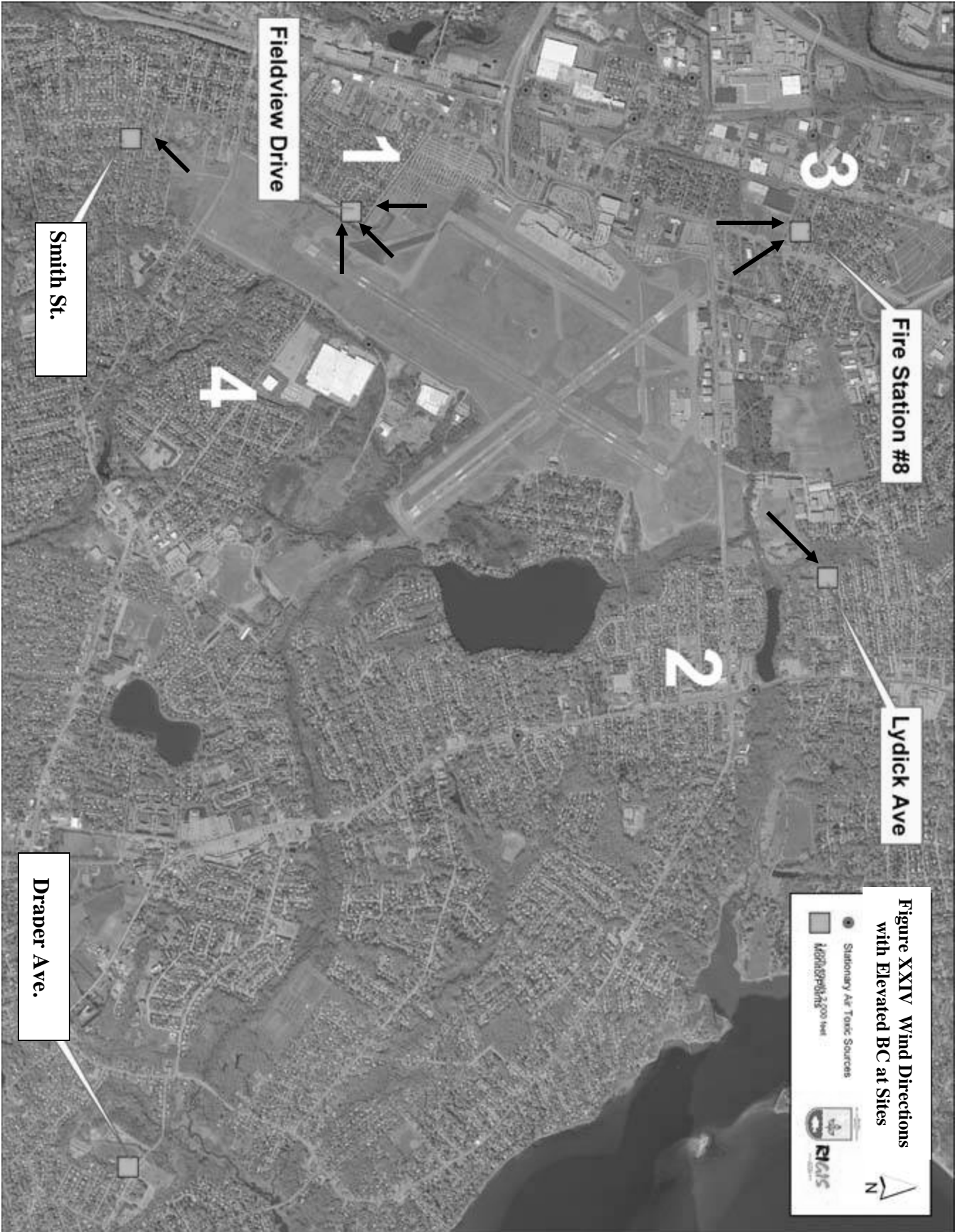


Figure XXV Black Carbon Levels - N and E Wind - Elevated Levels at Field View

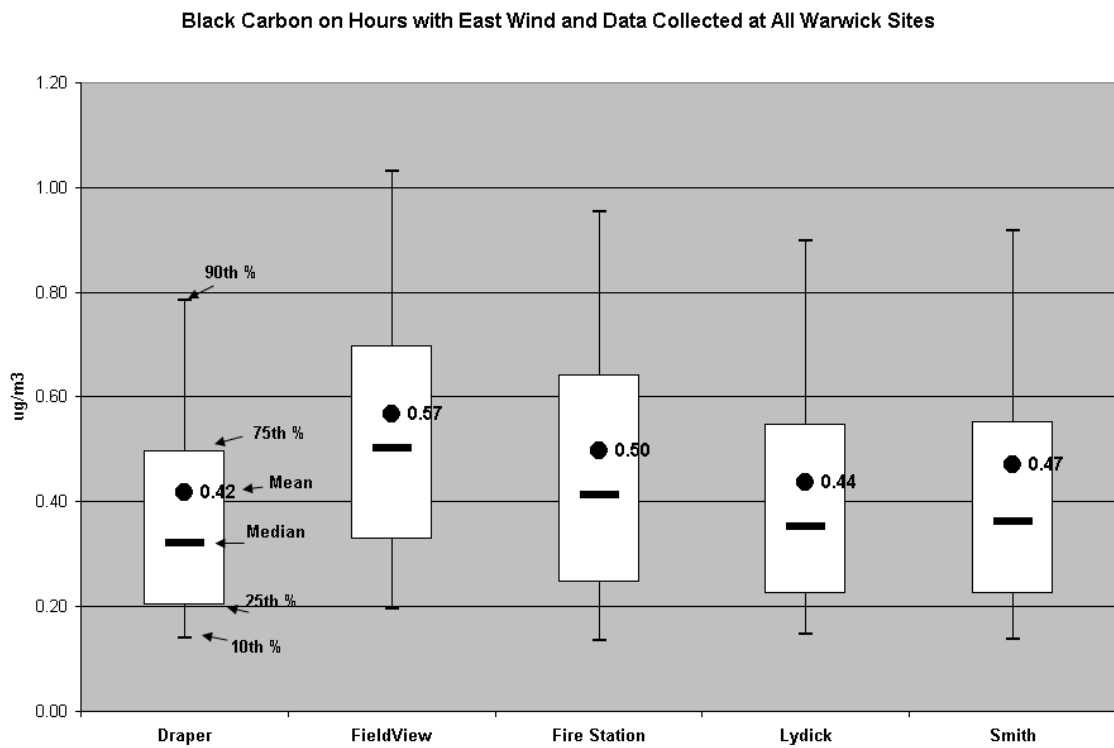
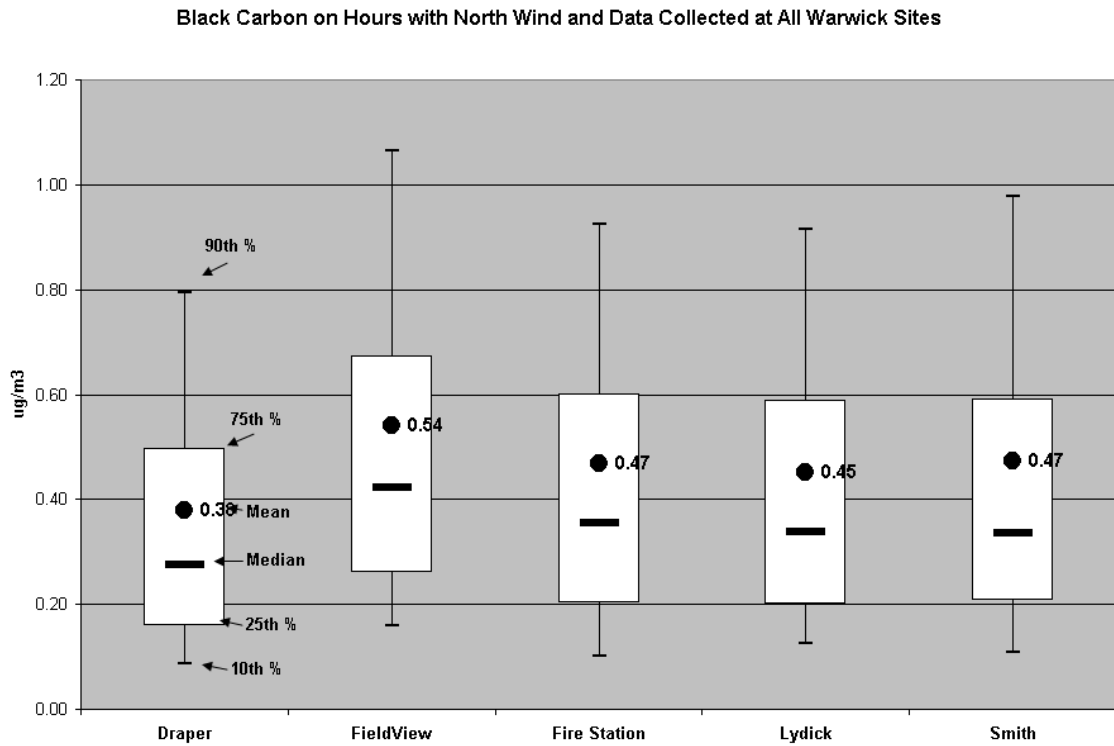


Figure XXVI Black Carbon - NE Wind - Elevated Levels at Field View & Smith

Black Carbon on Hours with Northeast Wind and Data Collected at All Warwick Sites

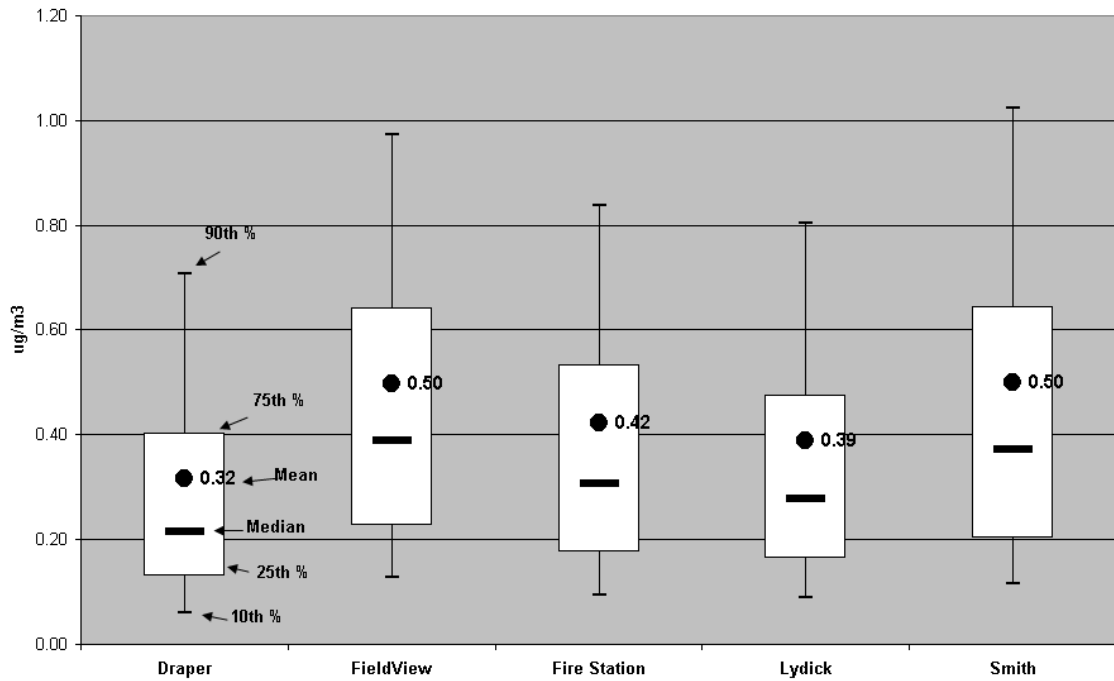


Figure XXVII Black Carbon - SW Wind - Elevated Level at Lydick

Black Carbon on Hours with Southwest Wind and Data Collected at All Warwick Sites

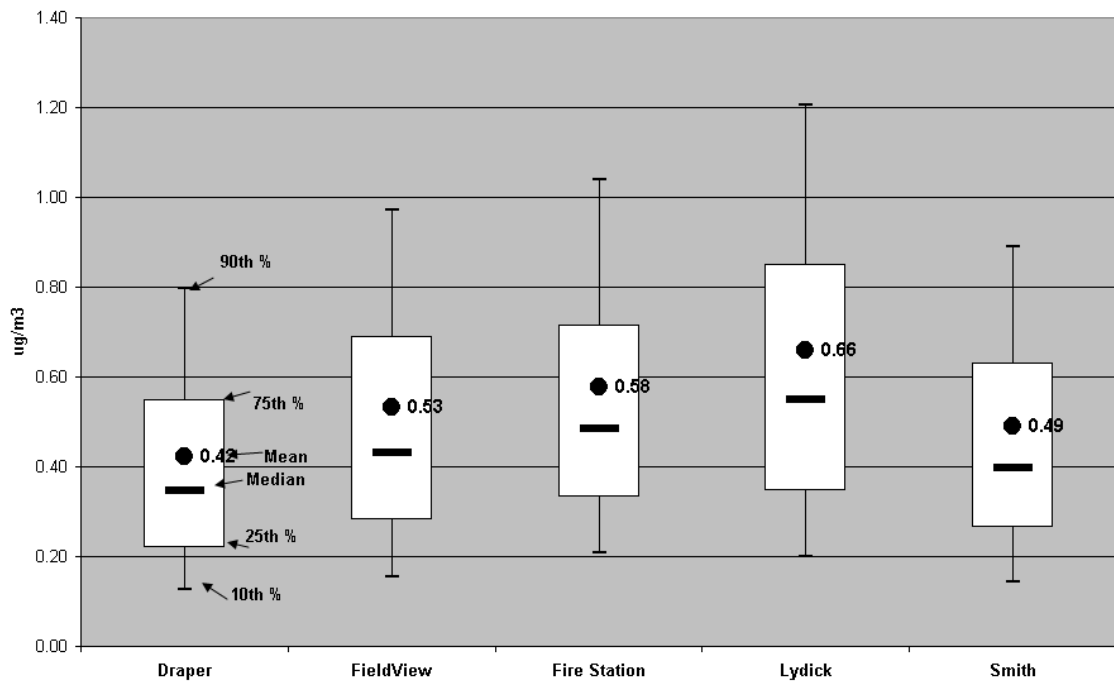
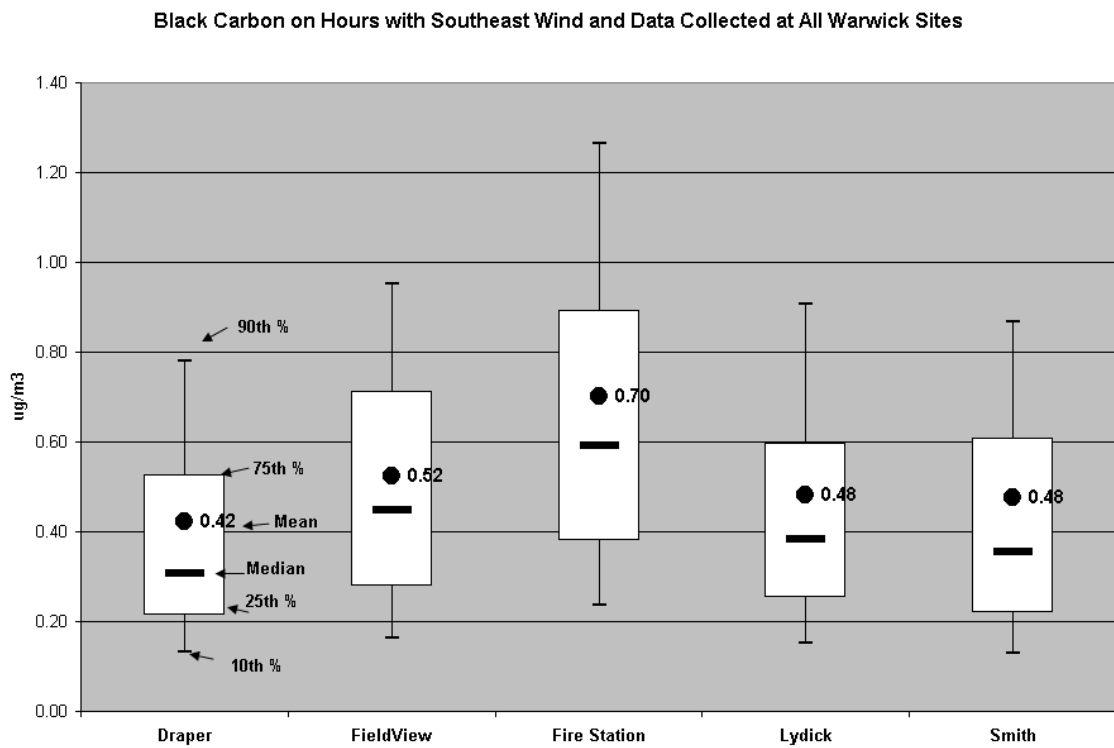
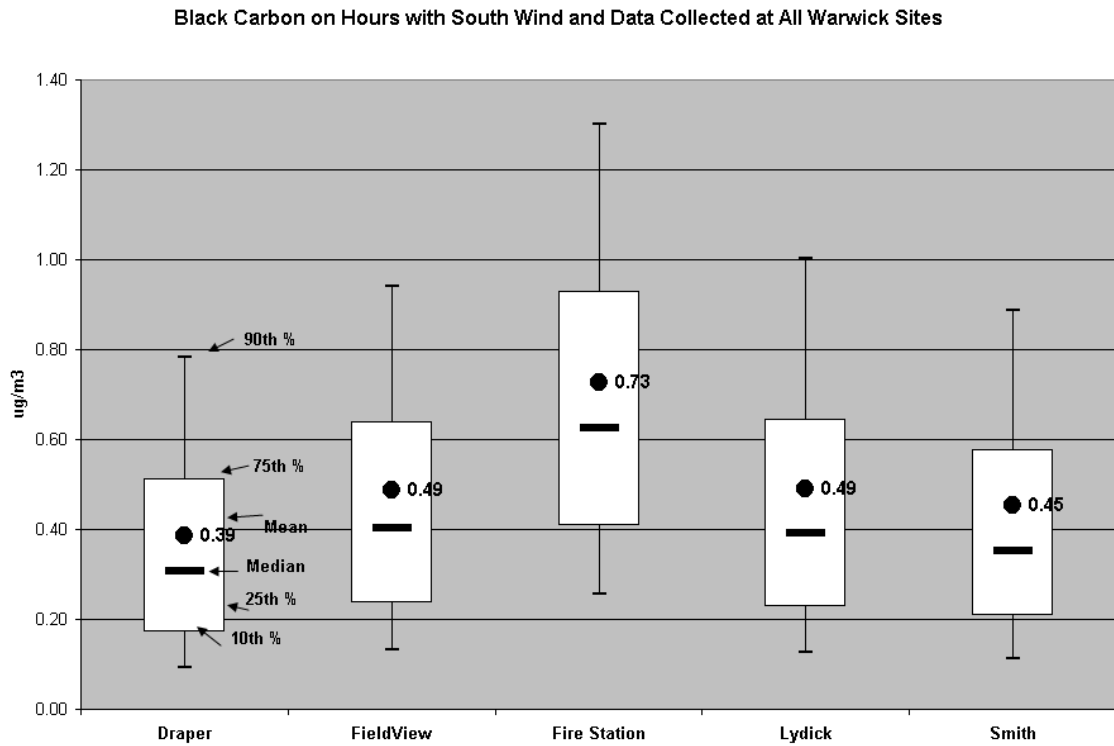
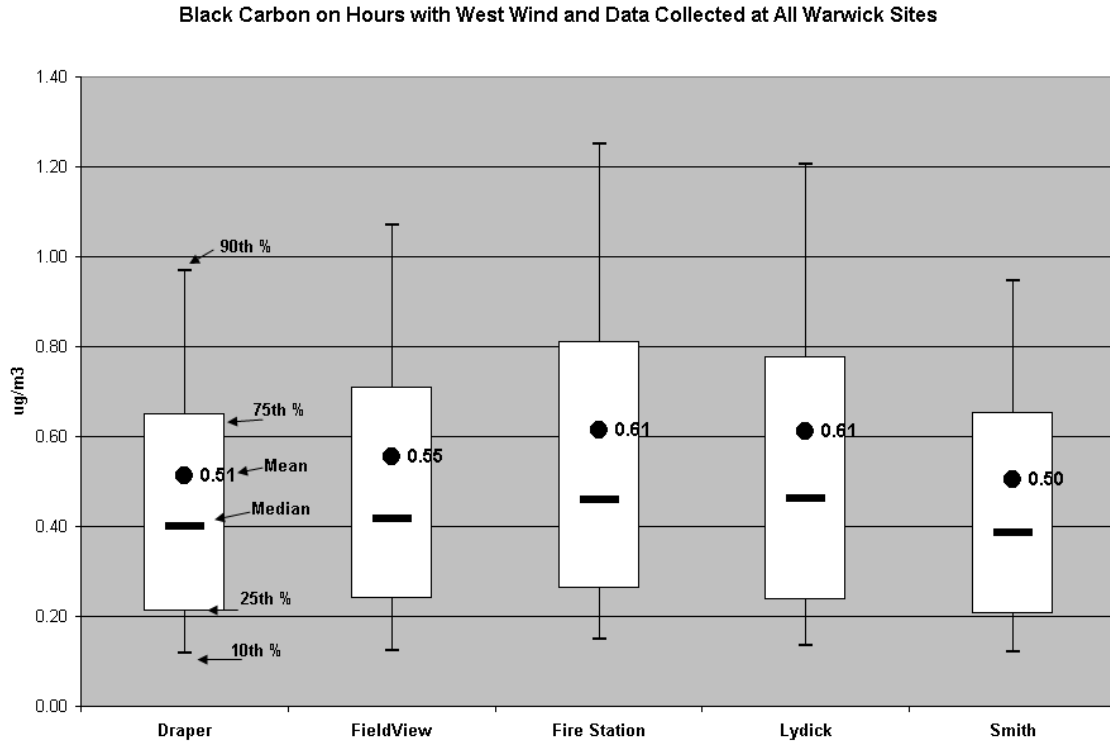


Figure XXVIII Black Carbon - S and SE Wind - Elevated Levels at Fire Station



Note that other sources besides the airport also clearly contribute to the Warwick BC levels. As shown in Figure XXIX, BC concentrations were, on average, higher at the Lydick and Fire Station sites than at the other sites when the wind was from the west.

Figure XXIX Black Carbon Levels - W Wind



In addition, it is interesting to note that, although average daytime BC levels were substantially higher at the Fire Station site than at the Lydick and Field View sites on weekdays, the concentrations at the three sites were essentially the same on weekends (see Figure XXX). Average BC at all sites were lower on weekends than on weekdays, but this difference was especially pronounced at the Fire Station; weekend average concentrations were, on average, 38% lower than weekday concentrations at the Fire Station and 26- 27% lower at Field View, Lydick and Smith. Since the average number of departing flights on Saturdays and Sundays are only 14% and 9%, respectively lower than the average on weekdays (see Figure XXXI), it appears that sources other than aircraft contribute significantly to the increased levels on weekdays, particularly at the Fire Station site.

Figure XXX Average Daytime BC Levels on Weekdays and Weekends

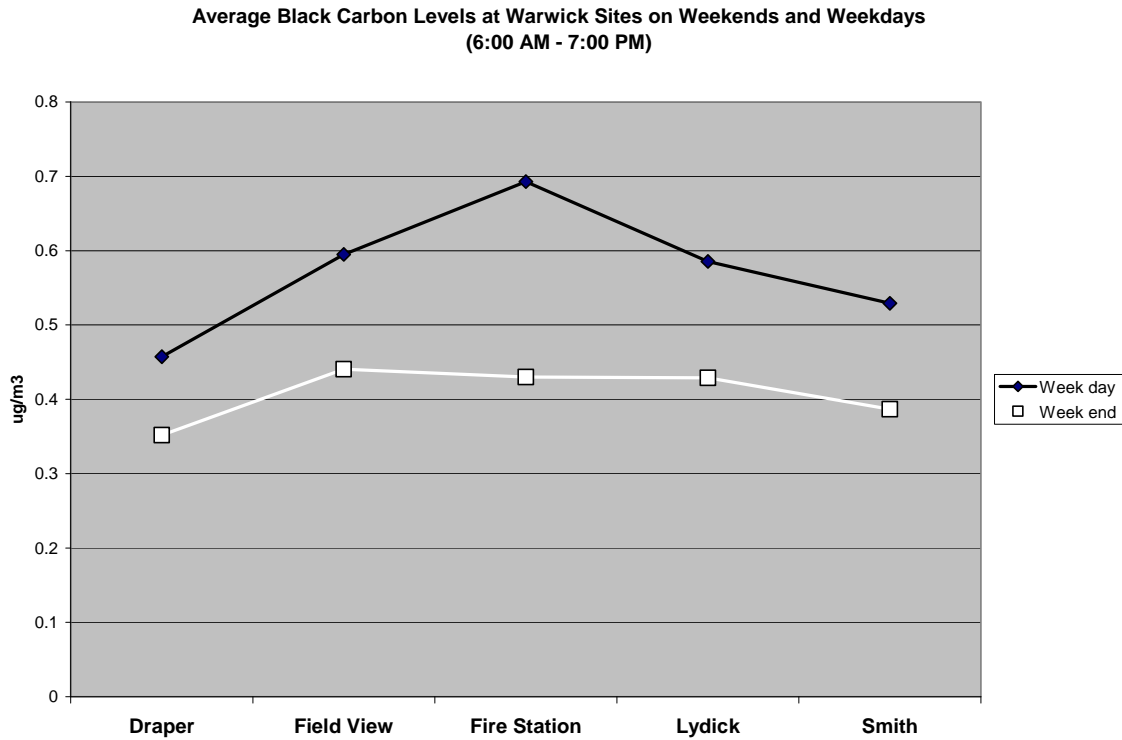
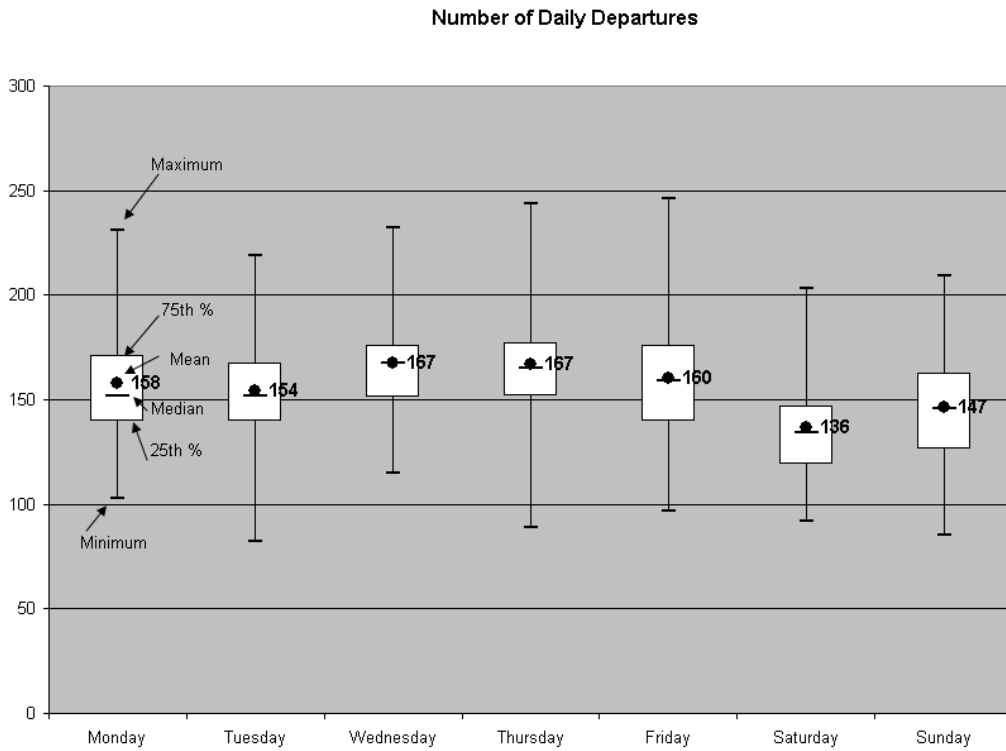


Figure XXXI Average Number of Daily Aircraft Departures by Day of Week

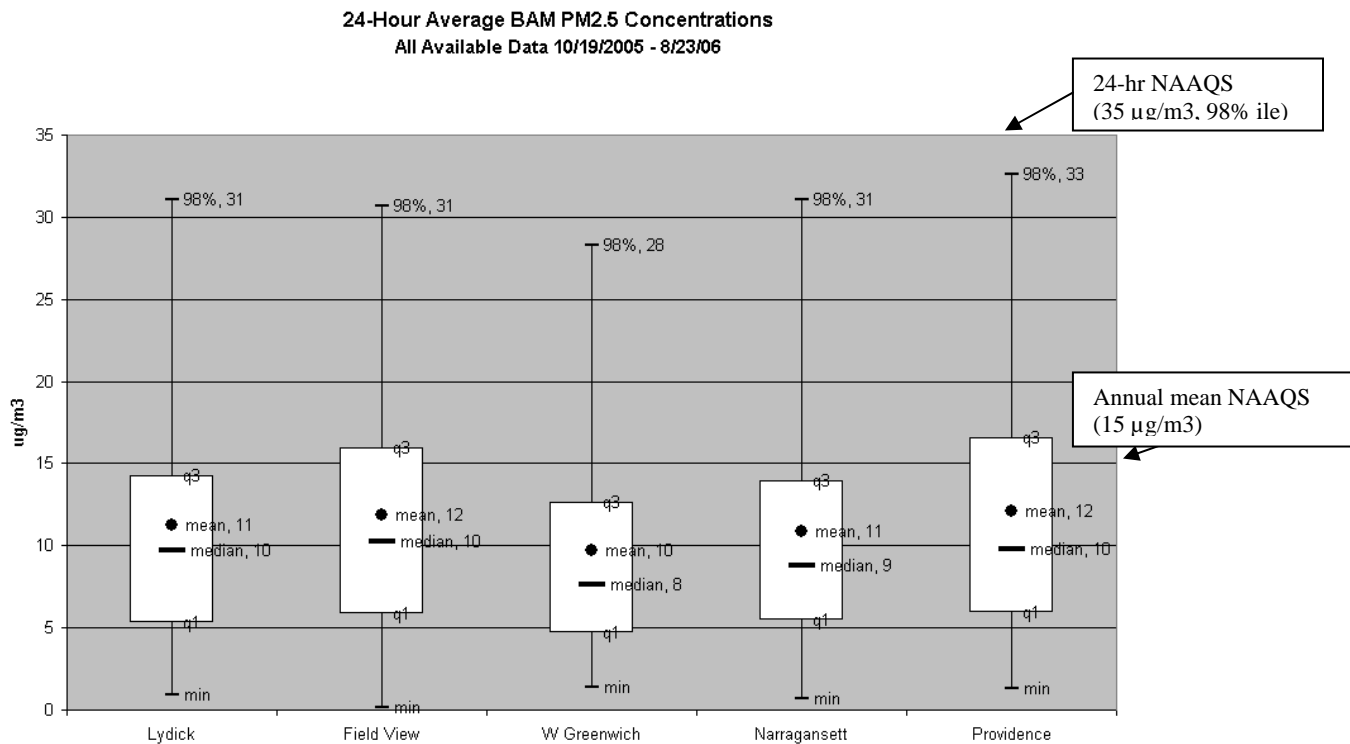


9.2.4 PM2.5

PM2.5 was monitored at the Lydick site from 4 May 2005 through 24 August 2006. PM2.5 was measured at the Smith site from 1 May 2005 – 19 October 2005, at which time the monitor was moved to Field View, where PM2.5 monitoring was continued until the end of August 2006. Monitoring was conducted with Beta Attention Monitors (BAMs), which record hourly PM2.5 concentrations. The following discussion applies to data generated during the time period that the Lydick and Field View monitors were both operational, 19 October 2005 – 24 August 2006. During that period, BAMs were also operated at three other Rhode Island sites, the urban Providence site, the rural W. Greenwich site and a coastal site in Narragansett.

As shown in Figure XXXII, mean and median PM2.5 levels measured at the Warwick sites were similar to those at the Providence sites. These concentrations cannot be compared directly to the National Ambient Air Quality Standards (NAAQS) for PM2.5, because BAMs tend to record higher PM2.5 levels than those measured by the Federal Reference Method monitors on which the NAAQS is based. However, even though the PM2.5 levels measured with the BAMs are likely to be higher than those that would be measured by the Federal Reference Method, they did not exceed the NAAQS, as shown in Figure XXXII.

Figure XXXII BAM PM2.5 Levels at Warwick and Comparison Sites



PM2.5 levels tend to have a large regional component and to be less clearly influenced by local sources than BC levels. As shown in Figures XXXIII and XXXIV, PM2.5 levels were slightly higher during the morning rush hour and were somewhat higher with low wind speeds than with higher wind speeds, but these effects were less pronounced than those seen for BC.

Figure XXXIII Weekday Diurnal Variation of PM2.5 Levels

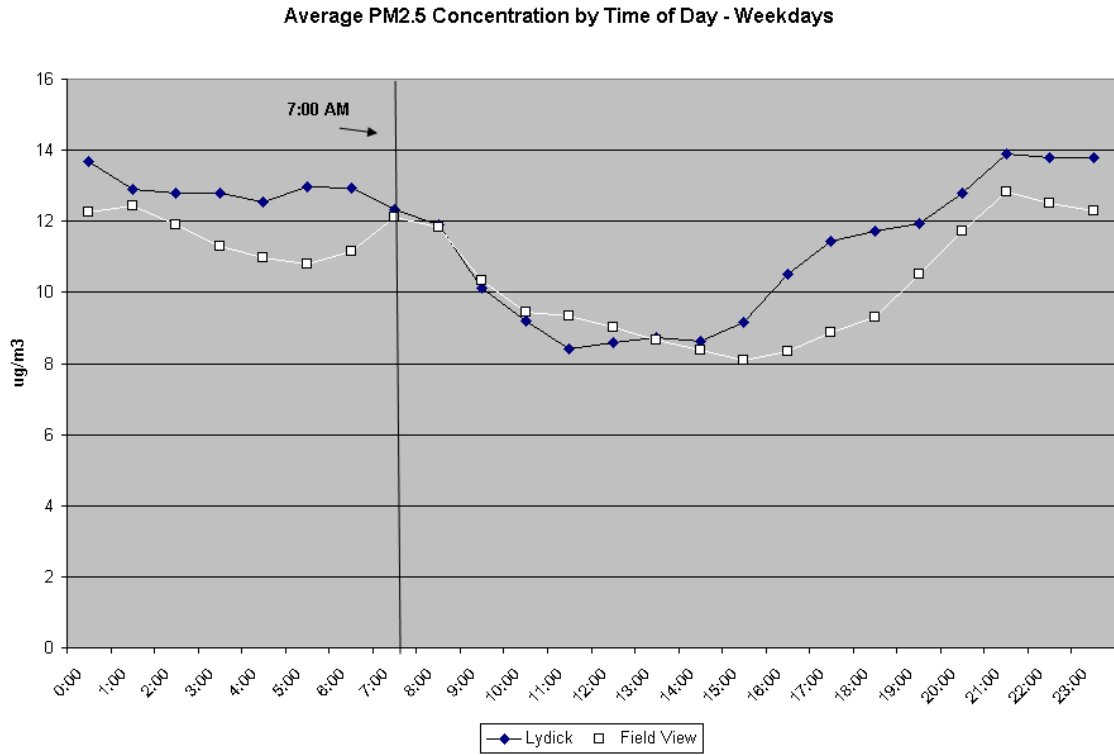
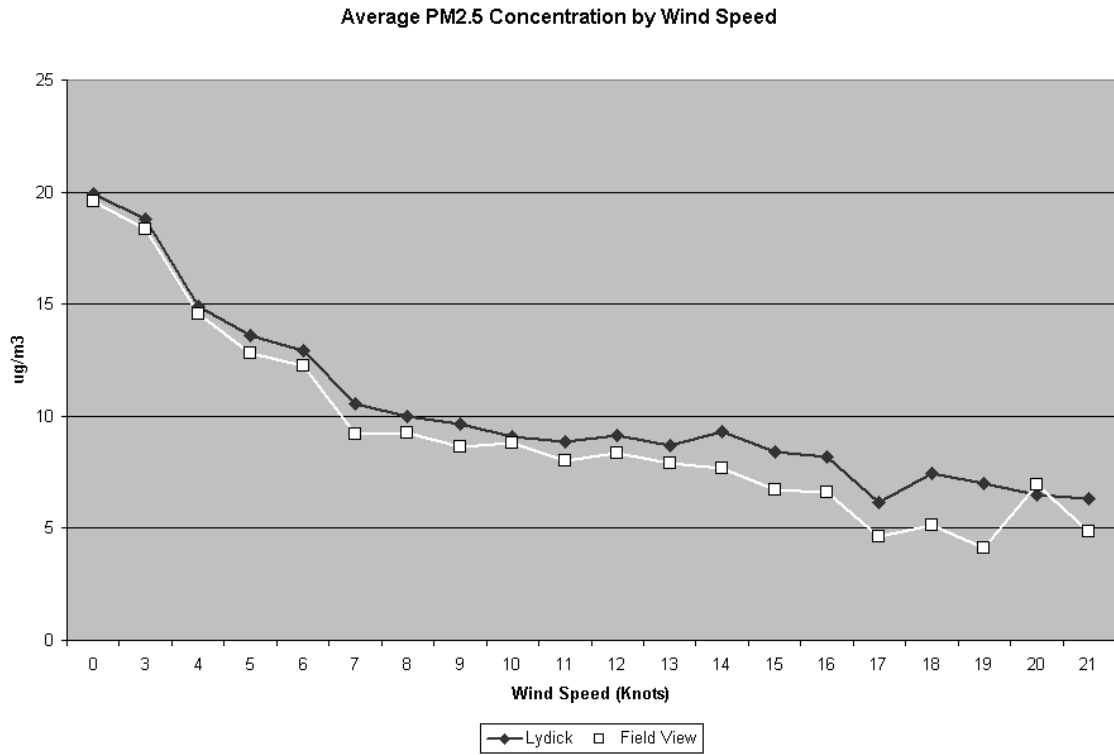
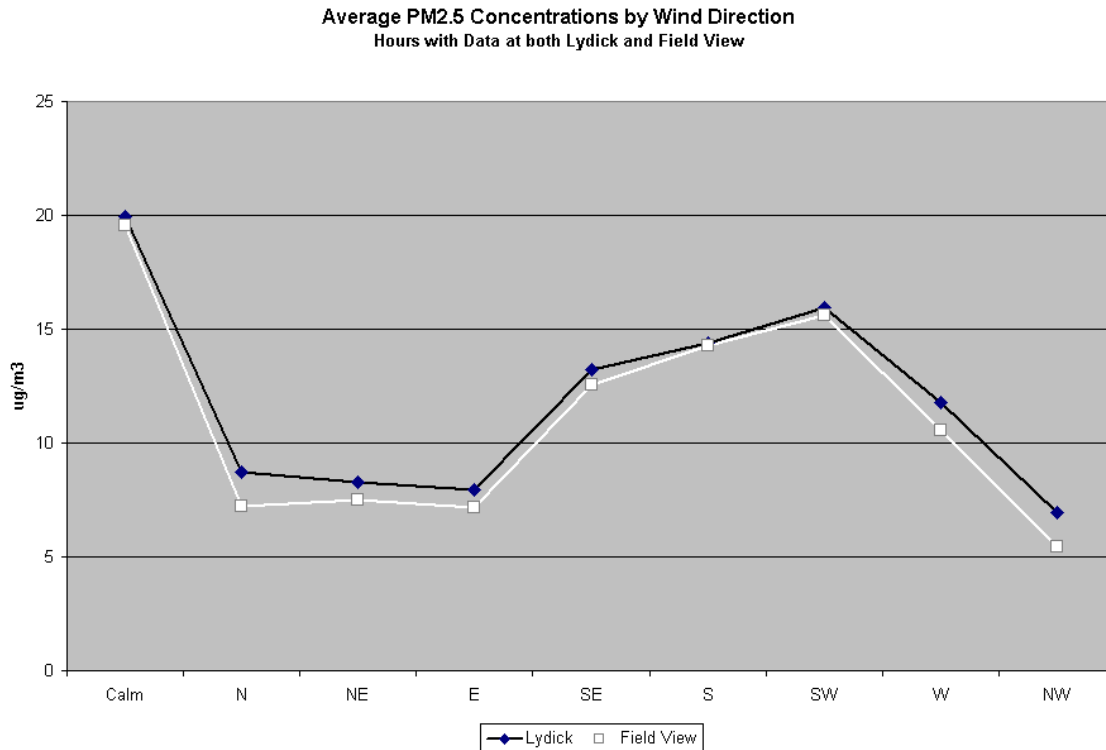


Figure XXXIV Relationship between PM2.5 Levels and Wind Speed



Unlike with BC, an analysis of PM_{2.5} levels by wind direction did not show a significant influence of airport operations on ambient levels of that pollutant. As can be seen in Figure XXXV, the PM_{2.5} concentrations at the Field View and Lydick sites were similar to each other with all wind directions. Concentrations were not higher at the sites when that site was downwind of the airport.

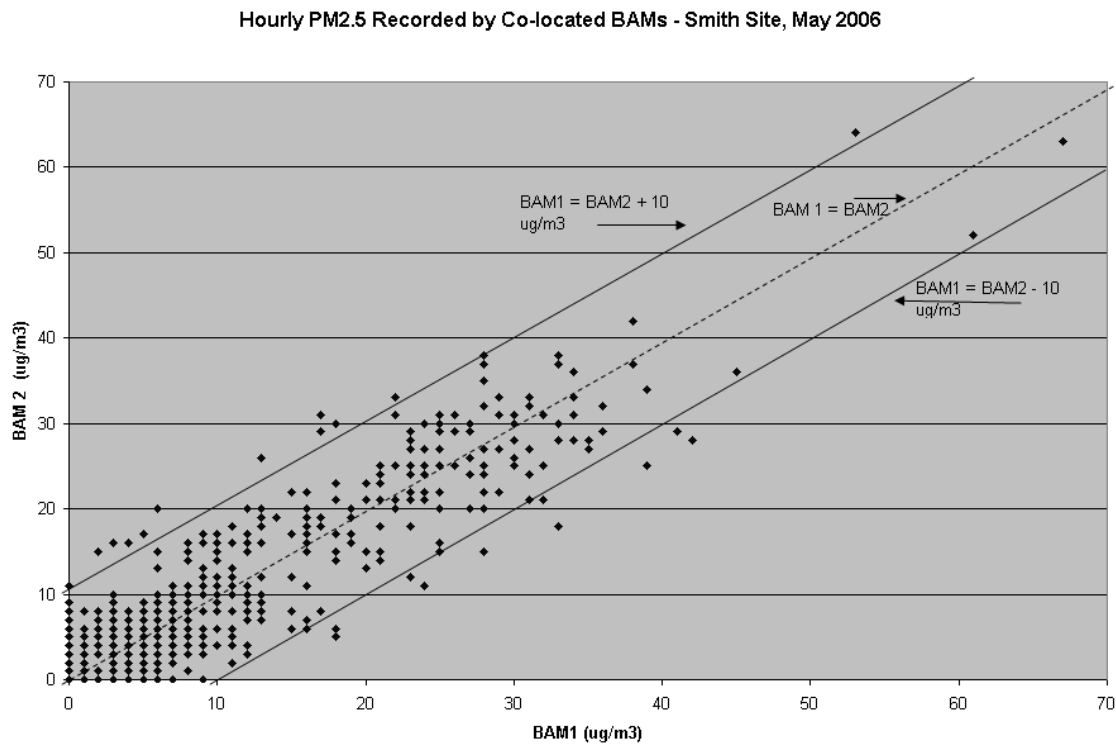
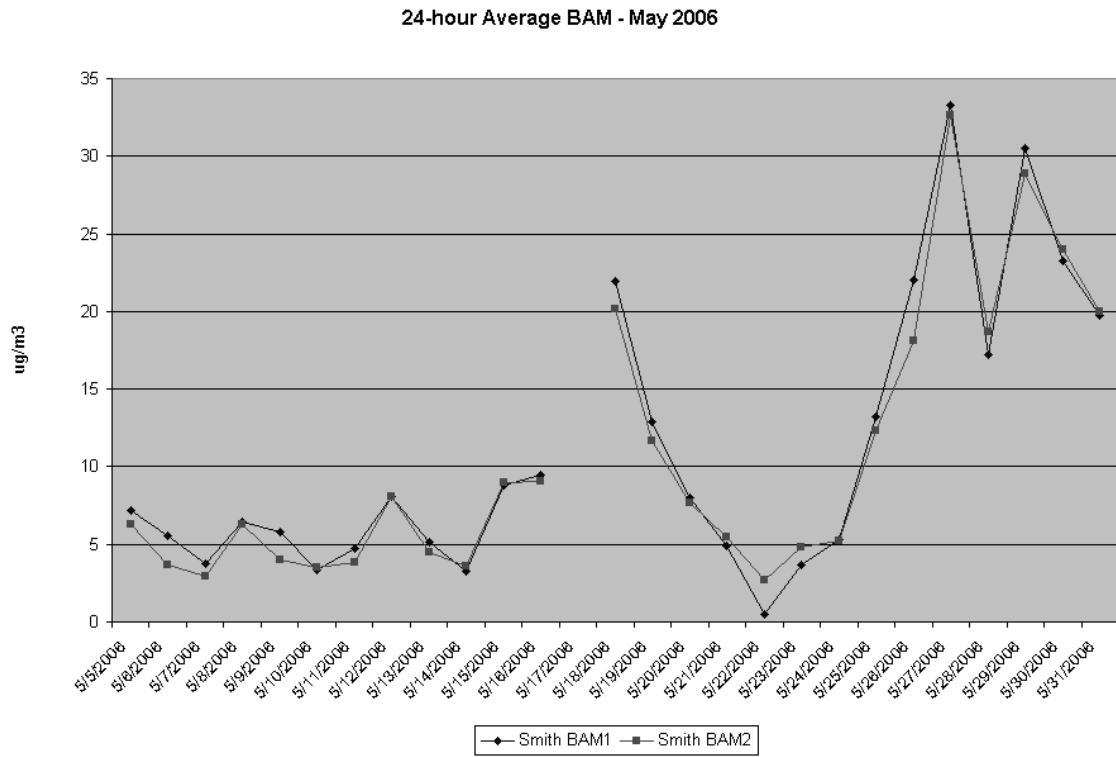
Figure XXXV Relationship between PM_{2.5} Levels and Wind Direction



As discussed above, a large portion of ambient PM_{2.5} levels are regional in nature. Detecting additional source-specific contributions to those levels, e.g. from the airport, would require the use of monitoring equipment that is much more accurate in short-term (e.g. one-hour average) measurements than the equipment used. The one-hour averages generated by the BAMs monitors used in this study were too influenced by background instrument noise to see subtle differences between levels at the monitors. Co-located BAMs monitors were operated at the Smith site during May 2006. Figure XXXVI shows that, although the 24-hour average concentrations generated by those monitors agreed well, hourly PM_{2.5} concentrations measured by the two monitors often varied by as much as 10 µg/m³. A variation of that magnitude would prevent the equipment from detecting a source-specific contribution to ambient PM_{2.5} levels if it did exist.

Therefore, although the study did not see an airport related affect on ambient PM_{2.5} levels in Warwick, such an effect may be seen if more accurate instrumentation were utilized.

Figure XXXVI Co-located BAM Agreement - 24-Hour Average and 1-Hour Average PM2.5 Levels



10.0 Quality Assurance/Quality Control (QA/QC)

RI DEM, in conjunction with the HEALTH Air Pollution Laboratory, submitted a Quality Assurance Project Plan (QAPP) for this project to the US EPA in March 2005; that document was approved by the US EPA Region I in November 2005. The QAPP relies on EPA audits and data certification to guarantee accuracy of sample analysis and on the collocated VOC samplers, carbonyl samplers and aethalometers operated at the Smith site to assure precision of those measurements.

10.1 VOC and Carbonyl QA/QC

The QAPP specifies the following goals for data completeness and precision of duplicate VOC and carbonyl samples:

VOC: Completeness \geq 85%
 Precision \leq 30% for samples with concentrations \geq 5 x MDL

Carbonyls: Completeness \geq 85%
 Precision \leq 20%

Data completeness for the one year periods for which data were presented above (9 June 2005 – 5 June 2006 for VOC and 1 September 2005 – 27 August 2006 for carbonyls) are shown in Table 7. Collection of carbonyl samples at the Draper site did not meet the completeness goal due to extensive problems with the sampling equipment at that site. Completeness for both parameters at the other sites and for VOC at the Draper sites was considerably higher than the minimum completeness criterion.

Table 7 Data Completeness - VOC and Carbonyls

	Draper	Fire Station	Field View	Lydick	Smith
VOC	98%	93%	97%	98%	98%
Carbonyls	56%	97%	97%	97%	95%

As discussed above, duplicate VOC and carbonyl samples were taken at the Smith site throughout the study period. Table 8 lists, for the VOC and carbonyl pollutants identified as potentially health significant, the percentage of the duplicate samples that conformed to the precision criteria specified above. Note that the VOC precision criterion applies only to samples with concentrations at least 5 times the MDL and, for the chlorinated solvents tetrachloroethylene and trichloroethylene, which had the lowest percentage conformance with the precision criterion, concentrations of virtually all of the samples were less than 5 times the MDL.

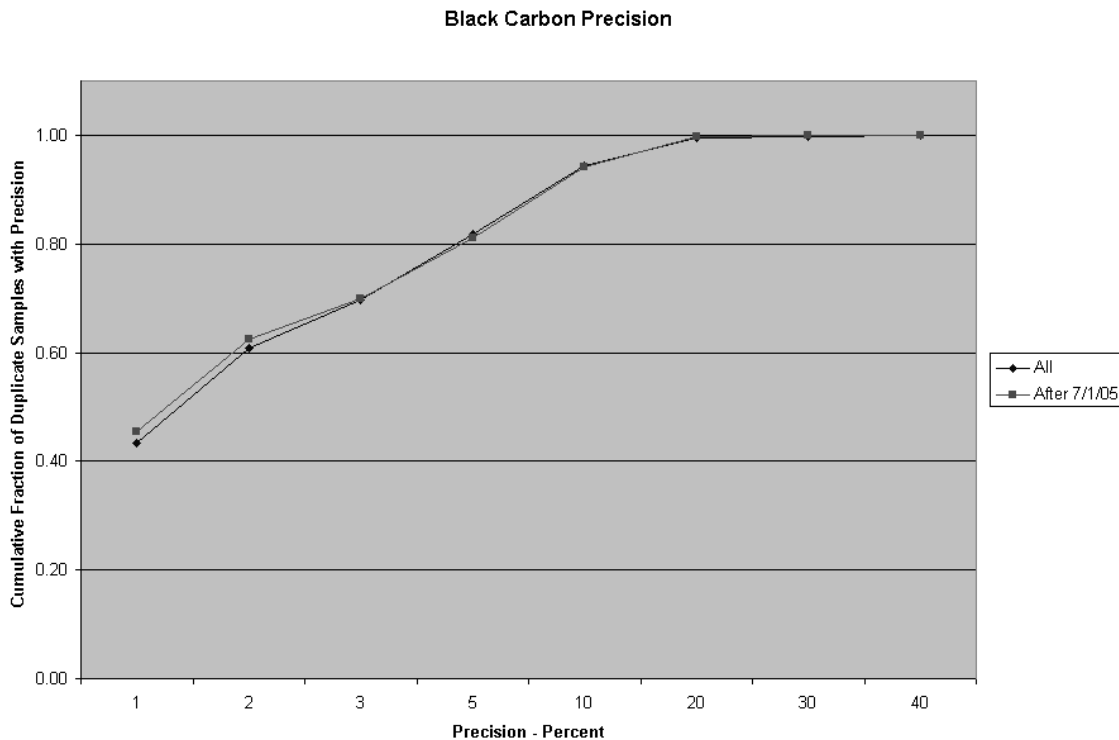
Table 8 Data Precision - VOC and Carbonyls

Chemical	Percent within Precision Criterion
VOCs	
benzene	100%
1,3-butadiene	98%
carbon tetrachloride	100%
chloroform	100%
dichloromethane	100%
tetrachloroethylene	94%
trichloroethylene	89%
Carbonyls	
Acetaldehyde	100%
Formaldehyde	100%

10.2 Black Carbon QA/QC

The QAPP does not list specific precision criteria for the aethalometer black carbon measurements. However, as can be seen in Figure XXXVII, the collocated aethalometers at the Smith site agreed very well. 84% of the collocated samples had a precision within 5% and 94% of the samples had a precision within 10%. RI DEM calculated the precision for the black carbon samples both for the whole study period and for the period after 1 July 2005 to determine whether start-up issues with the aethalometers may have affected the precision of the black carbon measurements in the early part of the study. Virtually no difference was seen, indicating that the data collected throughout the study period were acceptable.

Figure XXXVII Data Precision - Black Carbon



11.0 Open Path Optical System

As discussed above, the original study design included the operation of an optical beam system near the airport to try to collect continuous measurements of benzene, naphthalene, nitrogen dioxide (NO₂), sulfur dioxide (SO₂), toluene, xylenes, styrene and formaldehyde. A Cerex optical system was purchased for this purpose and was operated for approximately seven months in 2006 at a location on RIAC property immediately east of the main runway.

The system was purchased with a receiver (a UV spectrometer) and two UV light sources. One light source used a deuterium arc lamp, the other used a Xenon lamp. The deuterium lamp has a much weaker beam, but has a wider spectral emission range, allowing for the measurement of several desirable compounds that could not be detected with the narrower spectrum from the Xenon lamp. Another advantage of the deuterium lamp is that the beam contains very little visible light, making the system virtually undetectable to people in the vicinity, who might be bothered by the presence of a powerful, tightly collimated light beam. For these reasons, the deuterium lamp was tried in the field first. Since the maximum range of the deuterium lamp is 250 meters, the posts for the source and receiver were set at that distance. The cost of the installation was very high (about \$8000) and would have been higher if a longer path had been chosen.

The system was operated from January through April of 2006 with the deuterium arc lamp. During that time, the mounts for both receiver and source continually drifted out of alignment. The beam strength was only barely within the range deemed acceptable by the manufacturer, even when perfectly aligned. No useful data was obtained during these months. The target air toxics showed nothing but wildly fluctuating background noise that varied in the (implausible) ppm range. The only compounds that seemed to have a signal that meant anything at all were NO and NO₂. These compounds showed occasional pulses that probably corresponded to exhaust plumes from departing jets, but they came up out of a wildly fluctuating baseline that would be in the hundreds of ppb for a period of hours, and then went to negative-several-hundred ppb for a period of hours, as the system reset its reference spectrum. To obtain any useful information would have required excessive amounts of effort, for dubious results.

In June, the source and receiver were returned to the laboratory for cleaning. The system was then returned to the field, but with the xenon lamp in place of the deuterium lamp source. The new source was orders of magnitude brighter, and noticeable even at midday in June. From then on, there was never an alignment problem. The group of compounds was narrowed to the list of those that could be quantitated from the xenon source. We had hoped to start seeing benzene, as the manufacturer had seemed confident that we should be able to see it with the xenon lamp source. In fact, we still did not, perhaps because the path length was too short. The xenon source can be used at path lengths up to a kilometer, but we were limited to 250 meters, as that was the distance between the posts installed in January. The instrumentation was removed from the airport in September 2006.

The xenon lamp data looked about the same as the deuterium lamp data; with only NO_x pulses detectable on a wildly fluctuating baseline. Several packages of data were sent off to the manufacturer, as they claimed they had better software that could pull a signal out of the chaos that we saw from the software they provided us. However, the manufacturer was unable to retrieve additional data. Therefore, no useful data were gained from the use of this instrumentation.

12.0 Comparison of Monitoring Results with Model Predictions

The study objectives include a comparison of monitored levels to levels predicted by modeling conducted as part of the Environmental Impact Statement (EIS) for the proposed runway expansion. However, air toxics modeling was not included in the EIS submittal, eliminating the potential for this comparison.

The objectives also state that RI DEM would compare the monitoring results with the modeling results generated by the US EPA National Scale Assessment program. At the time that this report was prepared, the most recent available National Scale Assessment results used 1999 emissions data. Those modeling results were compared with the monitoring results generated by the TF Green study. Specifically, RI DEM compared the average concentrations of VOCs and carbonyls at all of the Warwick and comparison sites measured for the one-year periods with the maximum available data (9 June 2005 – 4 June 2006 for VOC and 1 September 2005 – 27 August 2006 for carbonyls) with the average levels of those pollutants predicted by the US EPA model for the census tracts in which the monitoring sites were located.

Table 9 shows the ratios of the monitored concentrations to the modeled concentrations for each Warwick and comparison site. Modeled values were within 50% of the monitored values (ratios 0.5 – 1.5) for many of the pollutants.

Monitored concentrations of several of the mobile source pollutants (benzene, 1,3-butadiene, toluene, xylenes) were approximately one-half of the concentrations predicted by the model. As shown in Figure XXXVIII, that discrepancy was not as large at the Pawtucket site as at the other sites, because that site is immediately adjacent to the highway, while the modeled value is for the census tract centroid, not the near roadway location. The model predicted that concentrations of mobile source pollutants at Draper would be less than half those at the other sites, while, in fact, Draper mobile source concentrations tended to be 70% - 90% of those at the other sites.

In contrast, monitored concentrations of the two background pollutants that exceeded the cancer benchmark, carbon tetrachloride and chloroform, were close to twice as high as those predicted by the model for both the Warwick and the comparison sites (see Figure XXXIX).

Table 9 Ratios of Monitored/Modeled Mean Concentrations - Air Toxics

	Draper	Fire Station	Field View	Lydick	Smith	W Greenwich	Providence	E Providence	Pawtucket
Acetaldehyde	1.2	0.9	1.0	0.8	0.9		0.9	1.1	
Benzene	0.8	0.5	0.6	0.5	0.6	0.6	0.5	0.6	0.8
1,3-Butadiene	1.0	0.5	0.6	0.4	0.6	0.5	0.5	0.7	1.0
Carbon disulfide	2.2	1.3	2.0	1.3	1.7	1.8	1.5	0.9	1.8
Carbon tetrachloride	1.9	1.9	1.9	1.8	1.9	1.9	1.9	1.9	1.9
Chloroform	1.8	1.6	1.8	1.4	1.7	1.8	1.1	1.2	1.4
Chloromethane	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cumene	48	13	23	16	11	7	10	38	103
Dichloromethane	0.6	0.7	0.6	0.4	0.5	0.5	0.5	0.4	0.6
Ethyl benzene	1.3	0.6	1.0	0.6	0.9	0.7	0.8	1.0	1.5
Formaldehyde	1.9	1.3	2.0	1.2	1.3		1.1	1.2	
Hexane	1.6	0.8	1.1	0.6	1.0	1.0	0.9	1.1	1.4
Methyl ethyl ketone	3.3	1.6	2.0	1.2	1.7	5.0	1.6	1.9	1.9
MTBE	1.1	0.4	1.0	0.4	0.7	0.3	0.7	1.0	0.9
Styrene	5.8	1.2	1.9	1.2	1.4	0.4	1.1	1.4	2.5
Tetrachloroethylene	0.8	1.2	0.7	1.6	0.5	0.4	0.9	0.8	1.1
Toluene	0.9	0.5	0.8	0.4	0.6	0.6	0.5	0.6	0.8
1,1,1-Trichloroethane	0.07	0.06	0.06	0.05	0.05	0.07	0.04	0.06	0.05
Trichloroethylene	0.3	3.2	1.1	1.1	0.6	0.1	1.4	0.7	1.5
Xylenes	0.8	0.5	0.7	0.4	0.6	0.4	0.6	0.6	1.1

Figure XXXVIII Average Modeled and Monitored Levels of Mobile Source Pollutants at Warwick and Comparison Sites

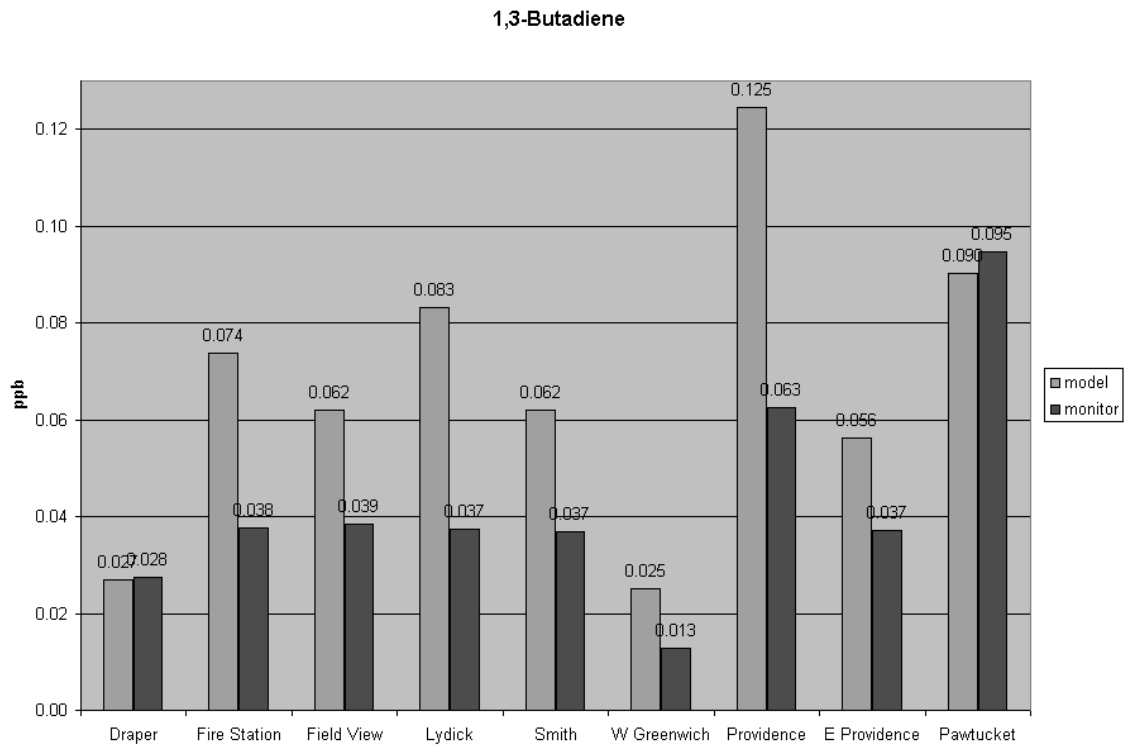
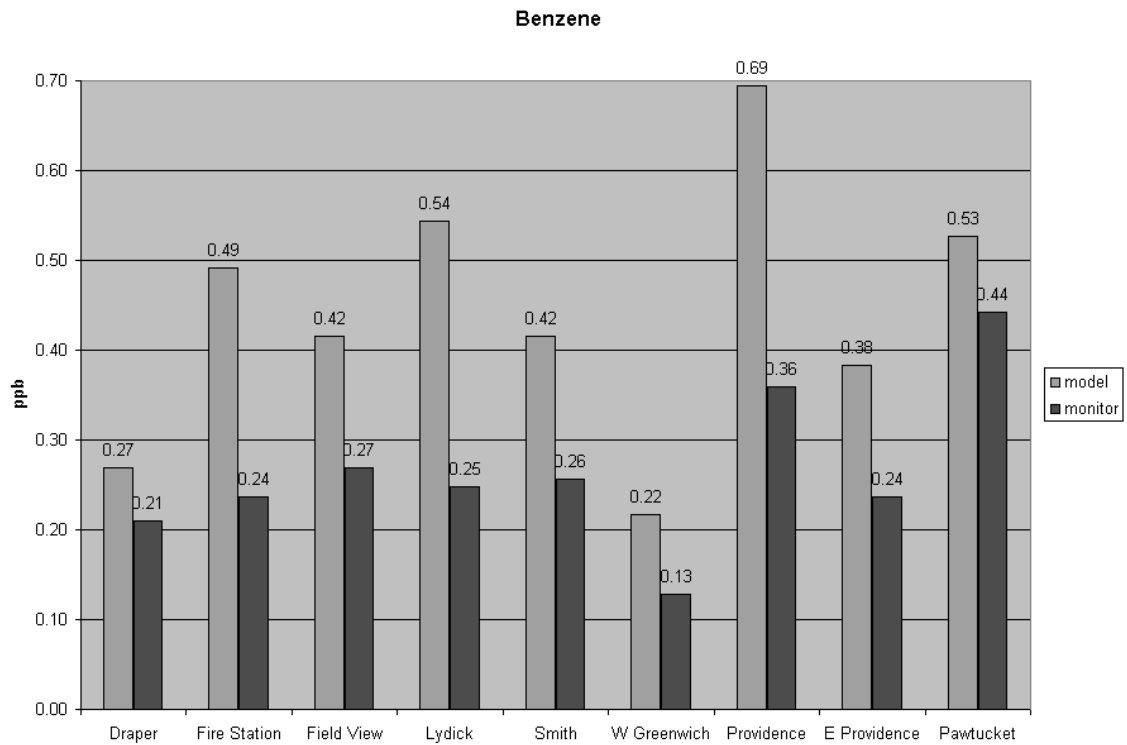
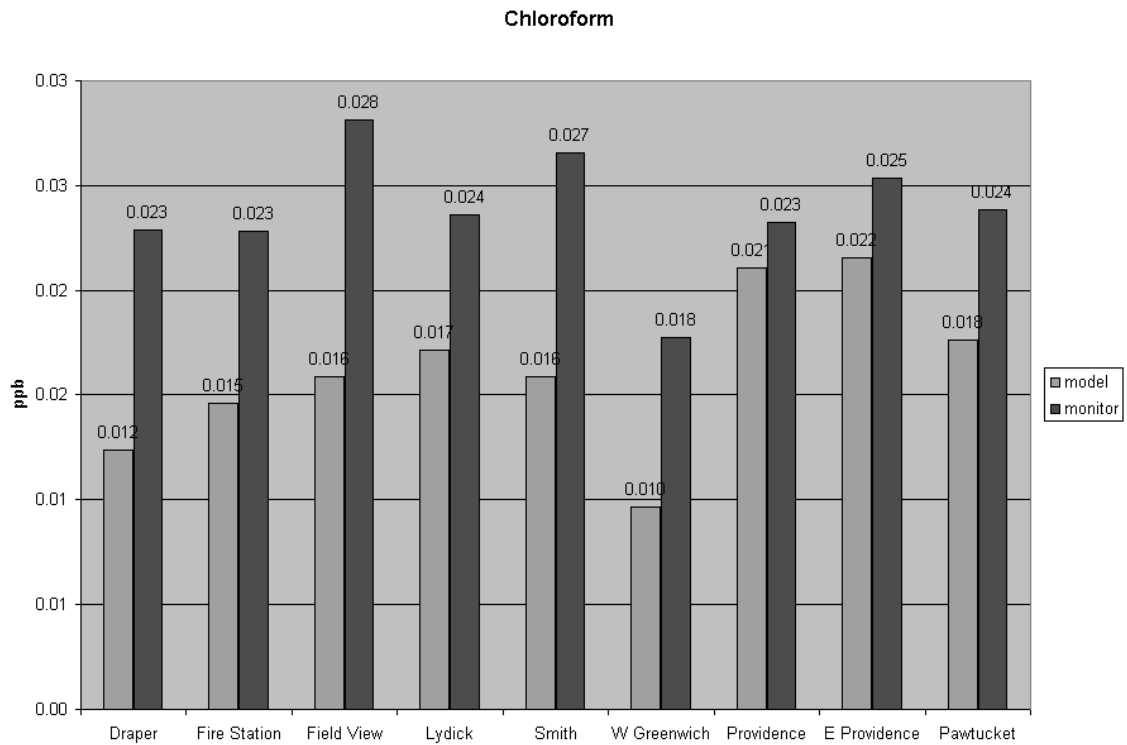
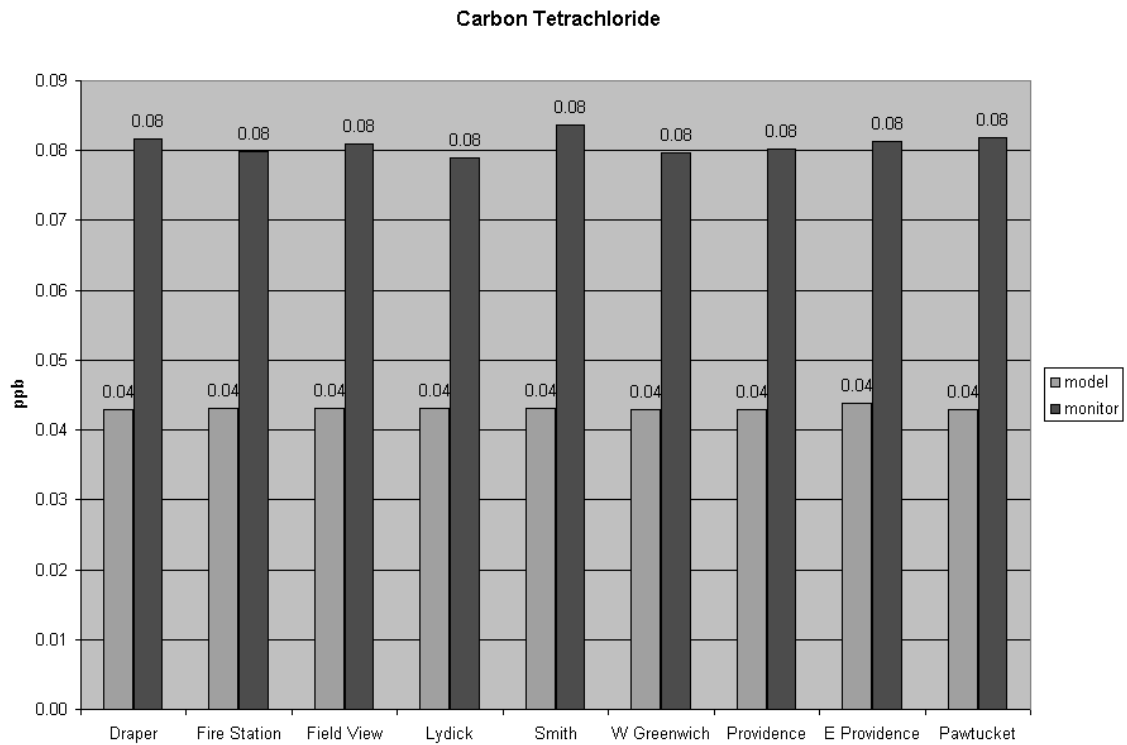
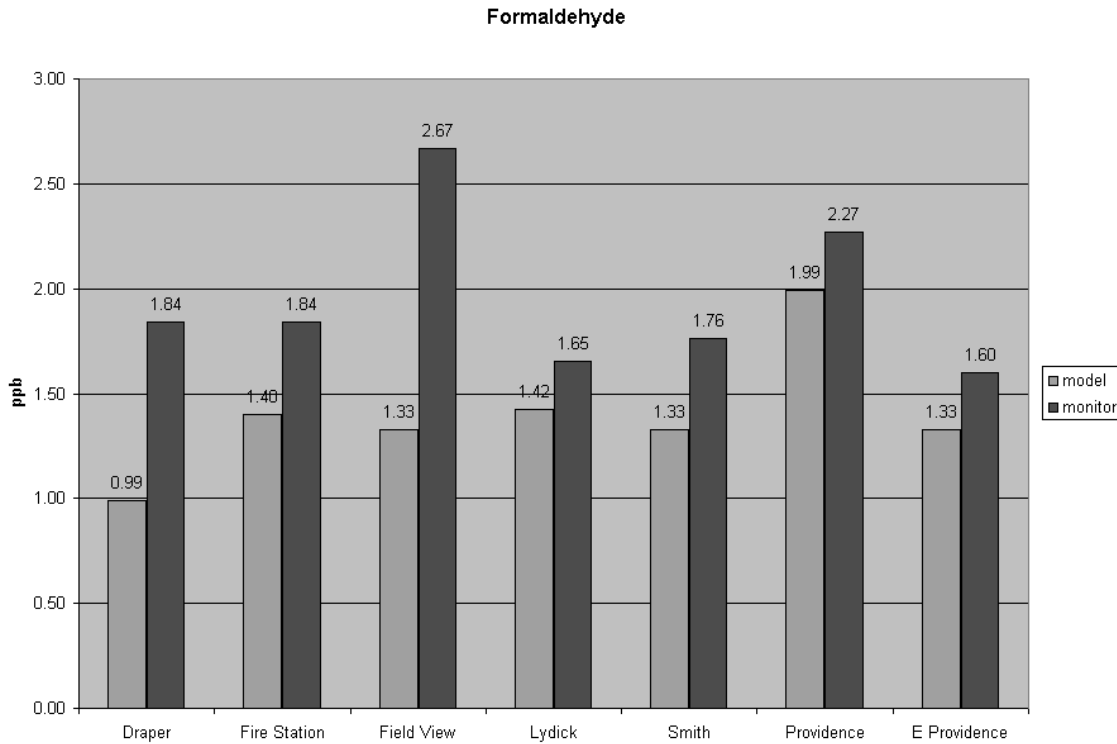


Figure XXXIX Average Modeled and Monitored Levels of Background Pollutants at Warwick and Comparison Sites



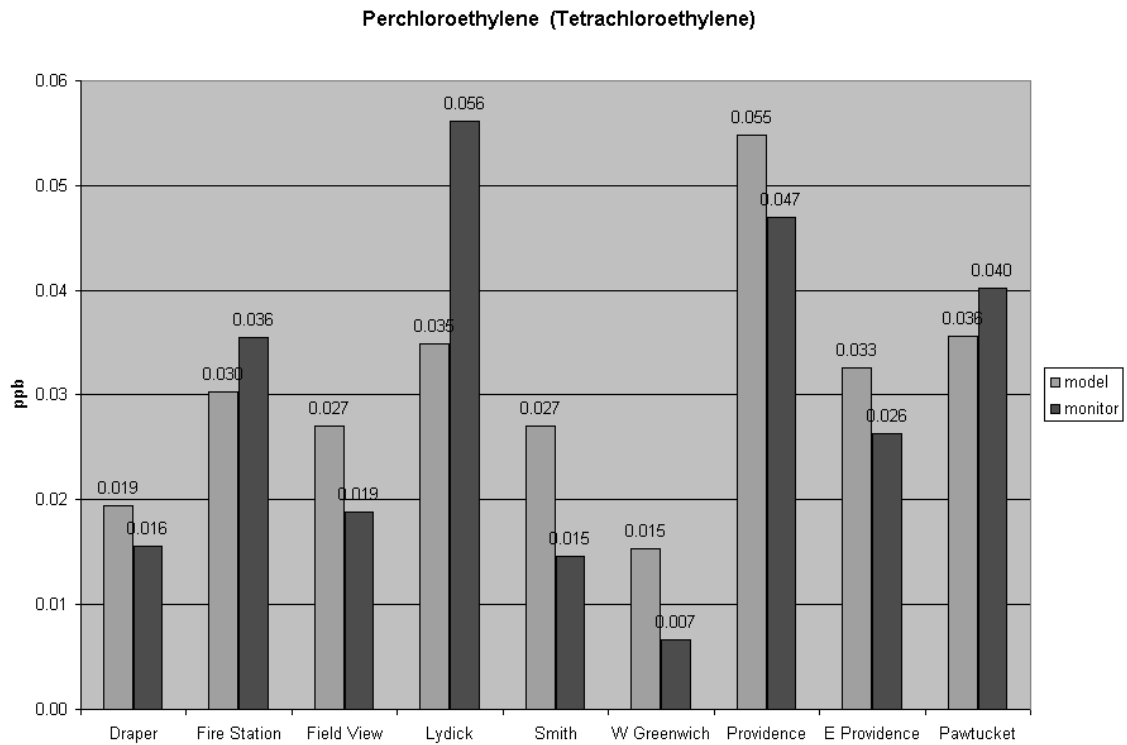
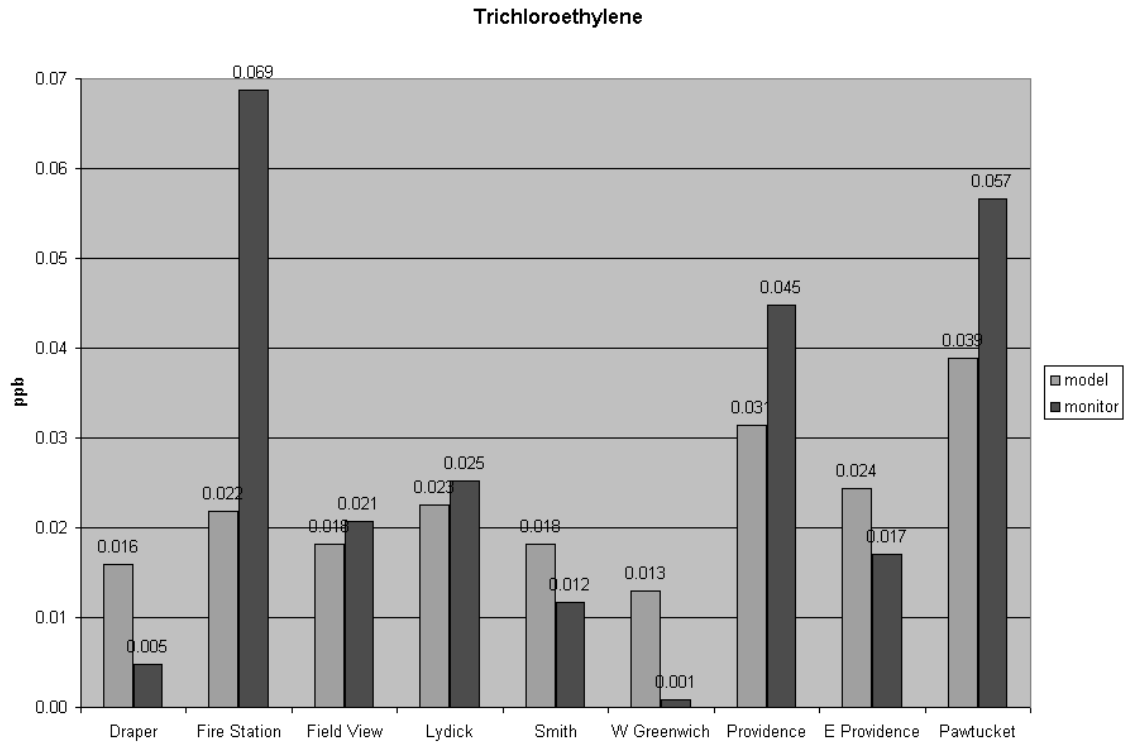
As shown in Figure XL, the model under predicted formaldehyde concentrations at all sites, but this under prediction was most substantial at the Field View and Draper sites. The model predicted formaldehyde concentrations at Draper 30 – 40% lower than at the other Warwick sites when, in fact, monitored concentrations of that pollutant were similar at Draper to those at the other Warwick sites. As discussed previously, monitored formaldehyde levels were considerably higher at Field View than at the other Warwick sites; this elevation was not predicted by the model.

Figure XL Average Modeled and Monitored Levels of Formaldehyde at Warwick and Comparison Sites



As shown in Figure XLI, the EPA model also did not predict the elevated levels of trichloroethylene seen at the Fire Station site and the elevated level of tetrachloroethylene (perchloroethylene) at the Lydick site. The monitored Fire Station trichloroethylene level was more than three times the modeled value and the Lydick monitored tetrachloroethylene level was 60% higher than predicted.

Figure XLI Average Modeled and Monitored Levels of Chlorinated Solvents at Warwick and Comparison Sites



13.0 Sea Breeze Effect

As discussed above, one of the reasons for locating the Draper site close to the Narragansett Bay was to investigate the possibility that, under certain meteorological conditions, sea breezes may cause elevated pollutant levels in coastal areas of Warwick. The “sea breeze effect” theory suggests that, when the prevailing winds have a westerly component and there are significant off shore breezes, areas of stagnant air may form near the coast which trap and concentrate the levels of pollutants emitted by upwind sources, like the airport.

The data presented in the results section show that the average levels of pollutants measured at the Draper site were not elevated relative to the other Warwick sites. In fact, the levels of mobile source related VOC, chlorinated solvents and black carbon at Draper tended to be lower than at the other Warwick sites, a finding that is consistent with the fact that the Draper site is not as close as the other sites to major roadways and industrial sources.

Although the average pollutant levels at Draper were not higher than those at the other locations, it is possible that the “sea breeze effect” may cause short-term pollutant elevations under particular meteorological conditions. To determine whether this was the case, RI DEM identified hours that the black carbon levels at Draper were higher than at both the Smith Street and Lydick sites. During 45% of those hours, the prevailing wind direction, as measured at TF Green, was from the west or northwest. In contrast, during the study period as a whole, winds from the west and northwest occurred only 29% of the time. This finding is consistent with a possible “sea breeze effect;” however, it is also consistent with the fact that the Draper site is downwind of a number of busy roadways and stationary fuel burning sources, as well as the airport, which may be impacting black carbon levels at the site when the wind is from the northwest - west .

As discussed above, meteorological data were collected at the Gorton School, which is across the street from the Draper Avenue site, beginning in September 2005. While wind speed data are available from that site, the wind direction data measured are not useable due to an error in equipment operation. Hourly wind speeds were, on average, 2 knots higher at the Gorton (Draper) site than those measured concurrently at TF Green. This was true also when the analysis was limited to the hours that the Draper black carbon levels were higher than those at Smith and Lydick. The frequency of stagnant (calm) wind conditions that would be associated with a “sea breeze effect” was not higher at the Gorton site than at TF Green, even during the periods when black carbon levels were higher at Draper than at the Smith and Lydick sites. Therefore, the wind speed data do not show evidence of a “sea breeze effect” in that area. Note that the wind speed measurement methodologies used at the Gorton School and TF Green were not the same so the data are not completely comparable.

In summary, RI DEM cannot rule out the possibility that the Draper site was, at times, affected by a “sea breeze effect,” since black carbon concentrations at that site were more

likely to be higher than those at Smith and Lydick when the wind was from the west or northwest. However, there are other possible explanations for that finding, and wind speed data for the Draper area do not show an increased frequency of stagnant air conditions which would cause the theorized pollutant trapping effect. Since the levels of VOC and black carbon tended to be lower at the Draper site than at the other Warwick sites, it is unlikely that any stagnation that may occur is causing significant air quality problems in the area near the Draper site. It is possible, however, that such effects may occur at other locations.

14.0 Next Steps

Several activities following-up on the results of the TF Green monitoring study are planned or underway. These activities include the following:

Further analysis of collected data RI DEM's analysis of the data collected was limited by the availability of staff time. In particular, RI DEM was unable to fully utilize the one-minute average black carbon data generated by the aethalometers. A group from the Harvard School of Public Health (HSPH) has received a grant from the Federal Aviation Agency (FAA) to apply regression techniques to those data to attempt to further identify black carbon sources. The data will also be used in conjunction with FAA modeling activities.

Source identification RI DEM has reviewed its emissions inventory to attempt to identify sources of chlorinated solvents that may have impacted the Lydick and Fire Station monitoring results. To supplement this information, RI DEM plans to conduct investigations in the areas around those monitors to identify sources as staff resources are available. Sources will be inspected to ensure that they are in compliance with RI DEM regulatory requirements.

Additional monitoring- RIAC In 2007, the RI General Assembly amended an existing law requiring RIAC to establish a long-term air monitoring system around the airport. To comply with the law, RIAC began interim monitoring in the spring of 2007 using four of the shelters RI DEM purchased for the TF Green study. Beginning in early 2008, RIAC will monitor for the following pollutants at the four locations, which include the Lydick, Field View and Fire Station sites and a site east of the airport:

- VOCs (Method TO-15)
- Carbonyls (Method TO-11a)
- PM2.5 (Federal Reference Method)
- Ultrafine particulate matter (particle counters)
- PAHs/semi volatiles (Method TO-13a and continuous particle-bound PAH monitors)
- Black carbon (aethalometers)

Additional monitoring- FAA/HSPH The HSPH group, funded by the FAA, plans to conduct 3 one-week sampling campaigns around TF Green in fall 2007 (already completed) and winter and spring 2008. At 2 fixed sites, continuous measurements of BC, PM_{2.5}, ultrafine particles, NO, carbon dioxide (CO₂) and meteorological parameters will be taken. At those locations, they will also collect 12-hour average samples for PAHs and nitro-PAHs, 6-hour average VOC samples and 24-hour average carbonyl samples. Palmes tubes will be used to collect 200 one-week integrated passive NO_x samples throughout the area to study spatial variations of pollutant levels.

In addition to the fixed site monitoring, the HSPH group plans to conduct mobile monitoring (on foot/in vehicle) to evaluate spatial variance of ultrafine particles, PM_{2.5}, BC and CO₂ in the neighborhoods around the airport. The purpose of the HSPH monitoring is to develop techniques to better determine the contribution of airport emissions to community-scale exposures and to build a model to estimate *de minimis* emission rates of air toxics from airports.

Additional monitoring – RI DEM RI DEM has been tentatively approved for a second US EPA Community Assessment grant to conduct follow-up monitoring around TF Green in 2008. The grant application focused on gathering data needed to further understand the health implications of the BC results in the first study, including collection of continuous data on levels of PAH, ultrafine particulate matter (particle count and surface area measurements) as well as BC and PM_{2.5} using nephelometers. In view of new RIAC monitoring requirements and FAA study, RI DEM plans to tailor the follow-up study so that it supplements rather than duplicates other efforts or, if it is determined that further data collection would not be useful at this time, to withdraw the grant application.

Health studies The 2007 airport legislation also required RIAC to provide up to \$200,000 to HEALTH over a 2 year period for health studies around TF Green. HEALTH's plans for these studies are still under development but are likely to include both a continued investigation of lung cancer data over time and an investigation of other potential health effects using hospital discharge, emergency room and other surveillance data in conjunction with monitored concentrations.

15.0 Conclusions

RI DEM was able to meet a number of the objectives that were identified at the beginning of the study. As discussed above, ambient levels of study pollutants in Warwick and comparison sites were characterized. The risks associated with those levels were calculated. Levels of formaldehyde at the Field View site, of tetrachloroethylene at the Lydick site and of trichloroethylene at the Fire Station site were higher than those at the other Warwick sites and at the comparison sites. Monitored concentrations were compared to concentrations predicted by a US EPA modeling study and will establish a baseline that can be used in the future to evaluate the air quality impacts of changes at the airport over time.

RI DEM was less successful in definitively identifying the sources of elevated levels of air toxics. It was possible to definitely demonstrate that the airport significantly impacted levels of black carbon at the four sites near the airport.

As discussed above, this study has influenced a number of follow-up activities aimed at further characterizing air quality and health impacts around the airport and more definitively identifying significant emissions sources.

Appendix A

HEALTH Memo with Warwick Cancer Data

Memo

To: Ms. Helen Drew, Office of the Director
From: John P. Fulton, PhD
CC: Robert Vanderslice, PhD; Patricia A. Nolan, MD, MPH
Date:
Re: Preliminary Cancer Incidence Rates, Warwick, Rhode Island

Preliminary Information

Per your request, the Rhode Island Cancer Registry has constructed age-adjusted cancer incidence rates by census tract, for the City of Warwick, Rhode Island, using cancer case reports for calendar years 1987-2000. The data reveal a pattern of higher-than-state cancer incidence rates in certain areas of the City, caused in the main by elevated lung cancer rates, as indicated on the enclosed census tract map.

For your information, I also enclose the underlying lung cancer incidence rates. Caution must be exercised in their interpretation, as most are not differentiable from state rates at the $P < 0.05$ probability level.

Please note that the data accompanying this memo are still undergoing quality assurance checks.

I would be glad to discuss these findings further, at your convenience.

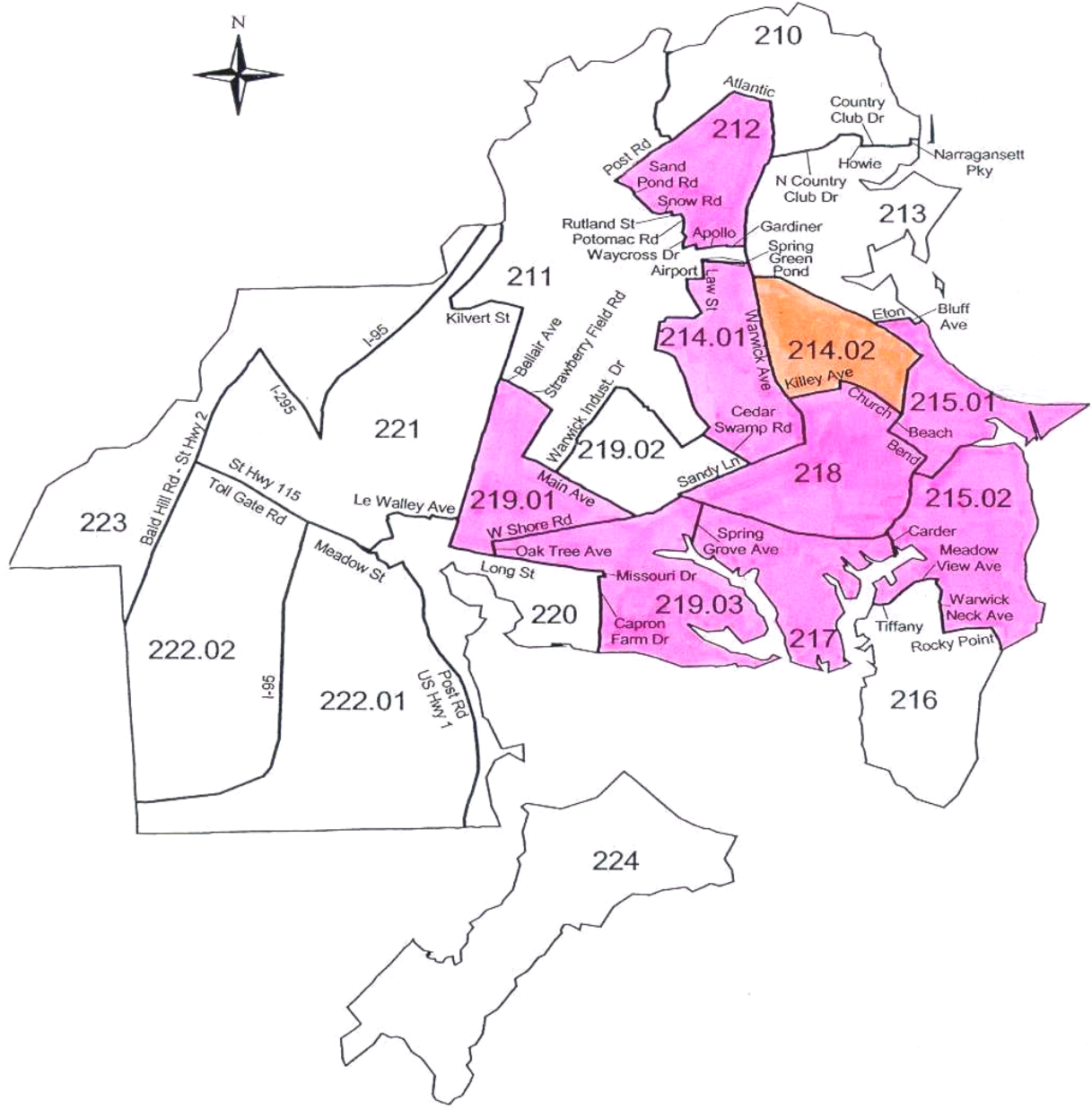
Attachments

- Map: Elevated lung cancer incidence by census tract, City of Warwick, Rhode Island

- Spreadsheet: Lung cancer incidence by census tract, City of Warwick, Rhode Island
- Methods used for rate construction

Census Tracts with Elevated Lung Cancer Incidence Rates, City of Warwick, Rhode Island

Period of Observation: 1987-2000



Lung Cancer Incidence Rates, City of Warwick, Rhode Island, by Census Tract and Gender

Period of Observation: 1987-2000

- Rates are average annual, age-standardized incidence rates
- Expressed as cases per 100,000 person-years of observation
- Using the United States 2000 standard million population.

	Male						Female					
	Cases	Pers-Yrs	Std Rt	1.96SE	Lo CL	Hi CL	Cases	Pers-Yrs	Std Rt	1.96SE	Lo CL	Hi CL
State →	6,881	6.85 M	106.8	2.5	104.3	109.3	4,850	7.42 M	55.0	1.6	53.4	56.6
Wrwk CTs												
021000	54	51385	96.8	26.0	70.8	122.8	48	59337	62.9	18.4	44.5	81.3
021100	38	35752	106.0	34.7	71.2	140.7	25	39601	50.9	20.3	30.6	71.3
021200	38	27202	127.7	42.7	84.9	170.4	40	30012	89.9	29.6	60.3	119.4
021300	44	34441	90.6	27.1	63.6	117.7	39	37482	69.9	22.6	47.3	92.5
021401	45	29333	144.5	45.6	99.0	190.1	33	32579	79.8	28.0	51.8	107.8
021402	35	26552	125.5	42.5	83.0	168.0	25	28416	66.2	26.6	39.6	92.8
021501	31	22401	161.1	58.1	102.9	219.2	26	23611	110.0	42.7	67.3	152.8
021502	39	30391	181.6	62.0	119.6	243.5	26	31202	91.0	35.5	55.5	126.5
021600	7	10321	73.0	57.6	15.4	130.6	6	10075	52.6	42.9	9.7	95.5
021700	39	35904	143.6	47.4	96.3	191.0	28	37043	86.5	32.2	54.2	118.7
021800	35	26891	146.1	49.9	96.2	196.0	27	30055	75.5	29.5	46.1	105.0
021901	38	28556	138.3	44.7	93.7	183.0	29	30761	84.6	31.2	53.5	115.8
021902	24	19400	125.3	51.8	73.5	177.1	14	20159	48.2	25.9	22.3	74.1
021903	38	29333	125.9	42.9	82.9	168.8	30	31407	75.2	27.3	47.9	102.5
022000	24	24623	108.7	44.7	64.0	153.4	20	26612	64.0	28.5	35.5	92.4
022100	53	35816	95.4	26.2	69.2	121.6	41	43003	48.6	15.2	33.4	63.9
022201	27	42518	68.6	26.6	42.0	95.3	24	44743	51.9	20.9	31.0	72.8
022202	29	17553	88.3	32.3	56.0	120.6	26	24690	33.5	14.2	19.3	47.8
022300	43	25127	121.0	36.9	84.1	157.9	29	31569	53.9	22.5	31.4	76.4
022400	7	15881	41.2	30.8	10.3	72.0	10	16465	61.1	38.1	22.9	99.2
	St+10%		117.5				St+10%		60.5			
	St+20%		128.2				St+20%		66.0			
	St+30%		138.8				St+30%		71.5			

Methods Used for Rate Construction

Incidence and corresponding standard errors are calculated using SEERStat, software produced for public use by the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute. The algorithms for rates, as described in SEERStat documentation, are as follows:

Crude Rate

A crude rate is the number of cases per 100,000 in a given population.

$$cruderate = \frac{count}{population} \times 100,000$$

Age-adjusted Rate

An age-adjusted rate is a weighted average of crude rates, where the crude rates are calculated for different age groups and the weights are the proportions of persons in the corresponding age groups of a standard population. Several sets of standard populations are included in SEER*Stat. These include the total U.S. populations (1940, 1950, 1960, 1970, 1980, and 1990), an estimate of the U.S. 2000 population, 1991 Canadian population, and the world population. The age-adjusted rate for an age group comprised of the ages x through y is calculated using the following formula:

$$aarate_{x-y} = \sum_{i=x}^y \left[\left(\frac{count_i}{pop_i} \right) \times 100,000 \times \left(\frac{stdmil_i}{\sum_{j=x}^y stdmil_j} \right) \right]$$

where count is the number of cases for the i th age group, pop_i is the relevant population for the same age group, and $stdmil_i$ is the standard population for the same age group.

Standard Error for a Crude Rate

This calculation assumes that the cancer counts have Poisson distributions.

$$SE_{crude} = \frac{\sqrt{count}}{population} \times 100,000$$

Standard Error for an Age-adjusted Rate

This calculation assumes that the cancer counts have Poisson distributions. Suppose that the age-adjusted rate is comprised of age groups x through y.

$$SE_{AgeRate} = \left[\sum_{i=x}^y \left(\frac{stdm\bar{l}_i}{\sum_{j=x}^y stdm\bar{l}_j} \right)^2 \times \left(\frac{count_i}{population_i^2} \right) \right]^{\frac{1}{2}} \times 100,000$$

Crude Rate Confidence Intervals

The endpoints of a $p \times 100\%$ confidence interval are calculated as:

$$CI_{low} = \frac{\left(\frac{1}{2} \left(ChiInv \left(\frac{p}{2}, 2 \times count \right) \right) \right)}{population} \times 100,000$$

$$CI_{high} = \frac{\left(\frac{1}{2} \left(ChiInv \left(1 - \frac{p}{2}, 2 \times (count + 1) \right) \right) \right)}{population} \times 100,000$$

where $ChiInv(p,n)$ is the inverse of the chi-squared distribution function evaluated at p and with n degrees of freedom, and we define $ChiInv(p,0) = 0$.

Although the normal approximation may be used with the standard errors to obtain confidence intervals when the count is large, we use the above exact method that holds even with small counts (see Johnson and Kotz, 1969, or Fay and Feuer, 1997). When the count is large the 2 methods produce similar results.

Age-adjusted Rate Confidence Intervals

Suppose that the age-adjusted rate is comprised of age groups x through y , and let:

$$w_i = \frac{stdm\bar{l}_i}{\left(pop_i \times \sum_{j=x}^y stdm\bar{l}_j \right)}$$

$$w_m = \max(w_i)$$

$$v = \sum_{i=x}^y (w_i^2 \times count_i)$$

The endpoints of a $p \times 100\%$ confidence interval are calculated as:

$$CI_{low} = \left(\frac{v}{2 \times rate} \right) \times \left(ChiInv \left(\frac{p}{2}, \frac{(2 \times rate^2)}{v} \right) \right) \times 100,000$$

$$CI_{high} = \left(\frac{v + w_m^2}{2(rate + w_m)} \right) \times \left(ChiInv \left(1 - \frac{p}{2}, \frac{2(rate + w_m)^2}{(v + w_m^2)} \right) \right) \times 100,000$$

This method for calculating the confidence interval was developed in Fay and Feuer (1997). The method produces similar confidence limits to the standard normal approximation when the counts are large and the population being studied is similar to the standard population. In other cases, the above method is more likely to ensure proper coverage.

Note

“Rate” used in the above formulas is not per 100,000 population.

Source

SEERStat Version 5.0.20, September, 2003.