Evaluating the Occupational and Environmental Impact of Nonroad Diesel Equipment in the Northeast

Final Report

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Northeast States for Coordinated Air Use Management
(NESCAUM)

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I. Study Overview and Findings

A. BACKGROUND

This study was conducted by the Northeast States for Coordinated Air Use Management (NESCAUM),[1] in collaboration with researchers from Keene State College (Dr. Melinda Treadwell) and the University of Massachusetts Lowell (Drs. Susan Woskie and Fred Youngs). The objective of this work was to evaluate the potential health risks from nonroad sources by monitoring selected hazardous air pollutant and particulate matter exposures in the cabin of operating nonroad diesel equipment and at the perimeter of the active work site. During the past decade, a number of analyses have concluded that mobile source air toxic emissions pose a significant public health threat across the entire nation. In the Northeast region, reviews of national computer modeling analyses and ambient air monitoring data have concluded that emissions from mobile sources are the dominant contributors to elevated ambient levels of several key toxic air pollutants. A number of analyses are ongoing to investigate important mobile source contributors and means to reduce these emissions. However, the contribution of nonroad heavy-duty diesel (HDD) equipment emissions in the region has been relatively uncharacterized. This study was undertaken in an effort to gather quantitative and qualitative evidence of the range of public health and environmental impacts associated with nonroad equipment operations in the Northeast region and to determine the significance of these exposures when considering the health risks for residents and equipment operators.

Diesel equipment emissions from the agricultural, construction (building and roadway), and lumber industries were examined. Initial pilot work was conducted at a construction site in June 2002. Site work was then conducted at a New Hampshire construction site and a roadway construction project, a lumberyard in Maine, a Vermont dairy farm, and a New York City construction site. Final field monitoring was completed May 29, 2003; complete data are presented in the appendices to this summary report. Manuscripts are under development and will be submitted for consideration by relevant peer-reviewed journals in the coming weeks and months.

For each location, the researchers used established federal methods to monitor the daily average exposures, and in some cases minute-to-minute exposures, to diesel soot, fine particulate matter ($PM_{2.5}$), and a suite of highly toxic gaseous pollutants, including acetaldehyde, benzene, and formaldehyde. In addition to these analyses, measurement techniques were used to provide qualitative and quantitative analyses of the metal content of selected $PM_{2.5}$ samples.

[1] NESCAUM is a nonprofit association of the eight air quality agencies of the Northeast states.

B. STUDY FINDINGS

1. In all locations, diesel equipment activity substantially increased fine particulate matter exposures for workers and nearby residents, in some cases by as much as 16 times. When comparing the integrated daily $PM_{2.5}$ concentrations collected in and around operating equipment at the three sites, concentrations were one to16 times greater than the average ambient concentrations normally recorded in each monitoring area. This observation underscores the adverse impact diesel equipment activity can have on air quality. In addition to increasing the average exposure to $PM_{2.5}$, short-term exposures at the perimeter of the site varied widely during the day. The peak concentrations observed during very active work may present *acute* health risks for workers and nearby residents.

With our growing understanding of the adverse health impacts associated with both acute and chronic fine particulate matter exposure, this finding also raises the concern of the potential adverse health impact for individuals working and living near worksites like those evaluated in this study.

2. Individual's estimated 24-hour exposures exceed the current air quality standard by nearly 2 to 3.5 times – substantially increasing workers' health risk.

In-cabin exposures to $PM_{2.5}$ for operators of monitored diesel equipment ranged from 2 $\mu g/m^3$ to over 660 $\mu g/m^3$ across the five sites evaluated. At the higher end of this monitored exposure range, if one were to average the individual's eight-hour workday exposure with the remaining 16-hours of the day at average ambient concentrations for that area, the 24-hour exposure would exceed the NAAQS by 1.9 to 3.5 times.

3. The most potent portion of particulate matter ($PM_{2.5}$) – *diesel* particulate matter – was monitored (as black carbon and elemental carbon) at levels that pose risk of chronic inflammation and lung damage in exposed individuals. In all five locations, diesel equipment activity increased diesel particulate matter exposure, average concentrations were one to six times greater than expected in urban and rural locations monitored in this study. The integrated daily average elemental carbon concentrations and real-time black carbon concentrations monitored at the sites were observed to be elevated by as much as six times above the concentration of diesel particulate matter normally expected in the monitoring locations. In all locations except New York City, no sources of fossil fuel combustion other than the monitored equipment and associated mobile sources were evident. Monitoring was conducted during non-heating seasons as well, so the background concentrations are expected to be low. Recently, scientists and regulatory agencies across the country and around the world have concluded that diesel exhaust and/or diesel particulate matter is highly likely to be carcinogenic to humans and causes pulmonary tissue damage following repeated exposures at low concentrations. Diesel particulate matter concentrations monitored in this study were, in some instances, above the established reference concentration (5 $\mu g/m^3$) in both the in-cabin and perimeter

samples.[2] Repeated exposures above this concentration are believed to present some risk of damage (i.e., chronic inflammation and histopathological changes) in the lungs of exposed individuals. When considering the potential carcinogenic risk(s) associated with diesel particulate matter, it is not clear that a “safe” exposure exists.

4. <u>As many as 200,000 workers may be exposed to these harmful concentration levels of nonroad equipment emissions in the Northeast region.</u>

Based on a recent nonroad equipment inventory completed in the Northeast, it is estimated that between 48,262 and 201,022 employees are exposed daily to diesel exhaust concentrations similar to those monitored in this study.

5. <u>Measured concentrations of acetaldehyde, benzene, and formaldehyde around the tested nonroad equipment operations were as much as 140 times the federally established screening threshold for cancer risk.</u>

In recent years, a number of national analyses conducted by the EPA have used computer models to predict ambient concentrations and exposures to a toxic air pollutants regulated under the Clean Air Act. Four pollutants resulting primarily from the combustion of gasoline – benzene, 1,3-butadiene, formaldehyde and acetaldehyde – have consistently been shown to exceed one in one million cancer health benchmarks across the country.[3] Benzene, 1,3-butadiene, and formaldehyde also each exceed one in one hundred thousand cancer risk thresholds in all urban areas in the Northeast. The results of this study suggest that nonroad HDD equipment operations can elevate levels of acetaldehyde, benzene, and formaldehyde in and around nonroad equipment sites.

6. <u>Concentrations of metals such as iron, nickel, and vanadium are elevated in samples collected around nonroad equipment. These metals are known to cause inflammatory responses and damage in pulmonary cells.</u>
The results of this study indicate that the concentrations of toxic metals observed in ambient $PM_{2.5}$ samples are increased when nonroad equipment is operating. These concentrations vary across sites and may present adverse health impact risks for workers and nearby residents. Metals such as nickel, vanadium, and iron are higher in samples collected in-cabin or near the perimeter of monitoring sites. These metals vary by location and may be of great significance when considering respiratory damage and potential long-term health effects.

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[2] This assumes, based on USEPA data, that diesel particulate matter constitutes between six and 36 percent of the ambient particulate matter concentrations nationwide and in urban areas. United States Environmental Protection Agency, Health Assessment Document for Diesel Engine Exhaust, USEPA/600/8-90/057F, May 2002.
[3] For cancer effects, the risk screening benchmarks used by the EPA reflect the assumption that there is no concentration below, which there is no risk (e.g., no threshold). The one in one million risk benchmark is an estimated exposure concentration, which would result in one excess cancer in one million individuals exposed for a lifetime.

II. Study Method

Note: For a summary chart of sampling methods and sampling locations, please refer to Appendix A of this report.

For each location, the researchers used established federal methods to monitor the daily average exposures, and in some cases minute-to-minute exposures, to diesel soot, fine particulate matter ($PM_{2.5}$), and a suite of gaseous pollutants including acetaldehyde, benzene, and formaldehyde. In addition to these analyses, x-ray fluorescence spectrometry and inductively coupled mass spectrometry were used to provide qualitative and quantitative analyses of the metal content of selected $PM_{2.5}$ samples.

Samples were collected in the cab of HDD equipment and at the perimeter of the worksite. The in-cab samples were collected to characterize occupational exposures for equipment operators.[4] The equipment type, model year, and horsepower for each site are shown in Table 1 below.

Table 1. Monitored Equipment Summary

Carmel, ME (Lumberyard)	Brattleboro, VT (Agricultural Operation)	Keene, NH (Building and Roadway Construction)	Manchester, NH (Roadway Construction)	New York, New York (Building Construction)
1986 Detroit, Mill Engine 200 HP	1979 Ford 6700 Spreader 256 HP	1999 JCB 4362, Front Loader 163 HP	1997 Caterpillar DR6xL Bulldozer 165 HP	1995 Komatsu PC100 Excavator 84 HP
1995 Pettibone Cary-Lift Super 15 Model #154D 130 HP	1976 Ford, Front Bucket Loader 250 HP	1998 Ingersoll Rand, Variable Reach Lift (Lull) 642B 80 HP	2002 Caterpillar It386 Loader, 145 HP	1988 Caterpillar 245B Drill (Excavator) 320 HP
1985 Detroit, Planer Engine 180 HP	1997 John Deere Tractor 170 HP	1997 Hyster Variable Reach Lift (Lull) 90 HP	1992 Caterpillar 235D Excavator, 145 HP	1988 Caterpillar 245D Excavator 320 HP
	1988 John Deere with Harrow 170 HP	1997 John Deere, 550 GTC Bulldozer 80 – 83 HP		

The worksite perimeter samples[5] (at the property boundary with nearby residential receptors) were also collected to characterize the near-field ambient air quality impact of worksite operations. Eight-hour integrated monitoring was conducted to quantify worker exposure to carcinogenic compounds of concern (i.e., benzene, 1,3-butadiene,

[4] Collected samples used appropriate absorbent media for the various analytes of concern and Gilian or SKC personal air sampling pumps or BGI Inc. cyclone pumps that were calibrated to draw an acceptable air volume across the sampling duration.
[5] Each site was approximately 300' X 300' square; perimeter sampling stations were positioned at the upwind and downwind edge of the site at the beginning of the monitoring day.

acetaldehyde, and formaldehyde), particulate matter ($PM_{2.5}$), and diesel soot. Real time sampling for $PM_{2.5}$ and diesel soot was also conducted at the worksite perimeter locations to determine whether peak, episodic exposures during a shorter averaging time might present a potential non-cancer health effect of concern in exposed workers or nearby residents.

After sampling, and post sampling pump calibration, the absorbent tubes and filter cassettes were removed from the air pumps, capped, bagged, and stored in a freezer (if appropriate) until analyzed. Analyses for this project were completed by: Environmental Research Institute (ERI), DataChem, the Scott Lawson Group, Keene State College, the University of Massachusetts-Lowell, and Dartmouth College, as described below.

<u>Carbonyl Analyses (EPA Method TO-11)</u>:
Samples for carbonyl compounds (monitoring targets: acetaldehyde, acrolein, and formaldehyde) were collected on 2,4-dinitrophenylhydrazine (DNPH-with ozone scrubber) coated SKC sorbent tubes (stock #226-120). In-cab or perimeter samples were collected using appropriately calibrated Gilian personal air sampling pumps. The cartridges used for these analyses were stored at a temperature less than 4°C before and after sampling. The carbonyl compounds react to form hydrazones, which are retained on the cartridge. The hydrazones are then extracted from the cartridge using a solvent and the extract is analyzed by high performance liquid chromatography (HPLC) with UV-visible detection by ERI personnel.

<u>Volatile Organic Compound Analysis (EPA Methods TO-17-UMASS-Lowell and TO-15-ERI):</u>
In-cabin exposures of benzene, 1,3-butadiene, ethyl benzene, and xylene were collected using Carbotrap X and Carboxen 1016 absorbent traps and were analyzed by UMASS-Lowell using thermal desorption mass spectrometry. Tubes are stored at less than 4°C before and after sampling.

A major goal for this monitoring project was to evaluate the range of organic compounds generated from nonroad equipment and the impact on worker exposure and ambient air quality. Therefore, in addition to the targeted breathing zone sampling with personal air sampling techniques, eight-hour average concentrations of volatile organic compounds were collected in cleaned, evacuated SUMMA canisters using eight-hour restrictive flow orifices. The SUMMA canister samples were analyzed by gas chromatography with mass spectrometry detection for compound identification confirmation. Laboratory standard operating procedures for the analytical laboratory performing TO-11 and TO-15 are included as Attachment I and II to this report.

<u>Organic and Elemental Carbon Analysis (NIOSH Method 5040):</u>
Eight-hour respirable particulate samples were collected in the cab of selected equipment and at the perimeter of the worksite using a BGI Inc. cyclone sampler and pre-fired pure quartz fiber filters. DataChem analyzed these particulate exposure samples to quantify the elemental carbon/organic carbon content. The quartz filters are heated to 900°C prior to sampling to remove all organic and elemental carbon adsorbed on the filter. The filters

are then sealed in special Petri dishes, which are then individually wrapped in foil to prevent adsorption of organic carbon during shipping and storage.

For analysis, a small punch from the filter (rectangular, 1.5 cm^2) is removed and placed it in a small tube furnace. The sample is heated from 25°C to 850°C in a pure helium (He) atmosphere to evolve the organic carbon. The carbon is oxidized to CO_2 then reduced to methane (CH_4) for detection by a flame ionization detector. The temperature is reduced to 550 °C and the atmosphere is changed to 2% O_2 in He. The heating continues to 850°C. The carbon evolved during this stage is elemental carbon. A correction is made for charring of the organic carbon in the later stage of the first temperature ramp, using the measured reflectance of the filter sample. The light reflected by the surface of the filter from a laser is measured throughout. This reflectance decreases as the organic carbon is charred. Upon switching the purge gas to 2% O_2 in He, the reflectance of the filter returns to its initial value. The carbon evolved during this segment of the analysis is defined as organic carbon and the results are reported accordingly.

Assessing the impact of equipment activity on monitored concentrations:

During the field monitoring studies described above, field-monitoring technicians prepared daily time activity diaries in 20-minute increments for each monitoring location (equipment and perimeter). These journals will record episodic exposures as well as general employee activities throughout the workday. The field technicians also recorded the type and activity of equipment used on the worksite during the day, the equipment horsepower, the fuel type and consumption data (if available for worksite), the hours of operation, and any unique duty cycle activities throughout the monitoring day that may later be correlated with episodic exposures peaks recorded by the real-time monitors for diesel soot and $PM_{2.5}$. Time activity diaries for each site monitored are presented in Appendix D.

Controlling variability in the study population:

The sampling goal of this study was to monitor similar equipment across the project worksites in an effort to increase the sample population per equipment type. Because the worksites monitored were similar, comparable types of nonroad equipment were available. As with all exposure monitoring studies, however, it was not possible to monitor all workplace conditions or all worker populations at each of the worksites. The original aim of the study was to characterize exposure to similar types of nonroad equipment between worksites, and to provide exposure/ambient impact data across a number of days at each site. These monitoring data provide ranges of exposure and ambient air quality impact across the study population that will ultimately be compared with ranges of potential adverse health endpoints. The monitoring approach is intended to provide quantitative evidence useful in estimating the potential public health impact in high-end exposed sub-populations and near-field residents at specific worksites. Further, quantitative monitoring evidence, when coupled with knowledge of the potency of monitored toxicants, and an understanding of the scope of nonroad construction activities in the region, will support a qualitative estimate of the potential regional impact of nonroad equipment activities. With respect to sample variability, the researchers anticipated the variability in worksite activities on any given day, difference in meteorological conditions during a sample collection period at a given site, and due to regional air mass transport the project team expected differences in the background concentrations of the compounds characterized in the study. By carefully recording twenty minute time-activity data for all monitored equipment each day on each site, by recording the minute-to-minute meteorological conditions on each day of monitoring at each site, and by evaluating state ambient air quality monitoring data across the region it is anticipated that variability in quantitative evidence will likely be controlled to some degree. Statistical analyses of the time activity data, real-time monitoring results, weather conditions, and integrated sampling results are being conducted and will be presented in a manuscript currently under development.

<u>Estimation of number of workers using heavy equipment</u>

In order to estimate the number of workers in the region operating heavy-duty diesel nonroad machines, three sources of information were used. The first source was Census Bureau employee data from 1997. The Census Bureau provides information on the number of employees in a variety of industry sectors. For this analysis, we took from the Census Bureau the numbers of workers in the region from several industry segments that use heavy equipment such as building construction, road building, mining, agriculture, and excavation. The second column in Table 2 (entitled *8-State Employees*) provides the number of workers in the region for each of the industry segments included in this analysis.

In order to estimate the number of pieces of equipment used per employee, we used NESCAUM survey data gathered as part of a recent study on construction equipment activity in the region. This data provided an estimation of the number of pieces of heavy equipment per employee for each industry segment. Columns 3, 4, and 5 of Table 2 provide the ratio of equipment to employees for three different counties studied. The survey showed that for some industries, such as Heavy Construction Contractors and Excavation & Demolition, the ratio of heavy duty diesel equipment to employees is high, while for other sectors, such as Lumber and Wood Products, the ratio of equipment to employees is relatively low.

The combination of equipment counts per employee and employees in each industry category can be combined to estimate the equipment operational in the eight-state NESCAUM region. Because some employees do not operate heavy equipment, but rather do office or administrative work, repair, or other functions, properly estimating the equipment/operator ratio is important to this analysis.

Once the number of employees was established and the equipment/operator ratio estimated, the number of hours each worker spends operating the equipment needed to be estimated.

Table 2. Ratio of Equipment to Employees in Three Counties

Description	*8-State Employees*	Equipment counts per employee		
		Franklin	**Providence**	**Albany**
Forestry	NA	0.00	0.25	ND
Nonmetallic Mining	9,093	0.63	0.13	ND
General Building Contractors	154,781	0.12	0.03	0.040
Heavy Construction Contractors	90,684	0.73	0.17	0.037
Specialty Trade Contractors	398,913	0.01	0.01	0.013
Excavation & Demolition	24,516	1.41	0.60	1.000
Lumber and Wood Products	32,954	0.02	0.01	0.000
Stone, Glass, and Concrete Products	52,685	0.09	0.04	0.051
Garden Supply & Nurseries	136,247	0.00	0.07	0.031
Landfills	6,854	NA	NA	NA
Scrap Metals	18,407	---	0.68	---
Municipal*	41,518,048 Population	0.001003	0.00004	0.00320

*Equipment counts as a function of human population

Information on hours of operation per piece of equipment was taken from both the NESCAUM survey and the EPA NONROAD model. The average annual hours of equipment usage (engine on) ranges from about 400 to 1,100 hours or about 20 – 50 percent of an average eight-hour workday.

Possible underestimation of exposed workers

The reason there is a wide range of workers exposed estimated in this study is due to the fact that some information key to the calculation was not available. It is important to note that the estimate of number of workers exposed to heavy-duty nonroad diesel emissions in this analysis likely underestimates the actual number of workers. The reasons for this are: lack of rental equipment data, other industry segments that use heavy equipment not well identified, and workers other than operators exposed to emissions from these pieces of equipment.

An important and growing industry category not characterized in the survey was the rental or leasing companies. This category could prove to be a significant source of equipment and has not been addressed in this analysis. There could be other industry categories not well characterized in the estimates presented here. Shipping (primarily around marine ports but other intermodal points as well) was another category not represented in these estimates.

In addition, equipment types other than construction and mining (such as forklifts, aerial lifts, generators) are used by construction and industrial operations but were not surveyed. As a result, the total equipment counts calculated above underestimate the diesel equipment operational within these industry categories.

Finally, operator worker exposure is only one element of the exposure at a construction site. Any number of supervisors, spotters, welders, and other workers are engaged in proximity to active construction and mining equipment.

III. Discussion

When evaluating the results of this study, one must be aware of the health endpoints being considered. A number of federal agencies develop occupational and environmental "safe" exposure guidelines for carcinogens and non-carcinogens and several are presented here for comparison. Agencies such as the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) are responsible for occupational safety and health for general industry or the mining industry, respectively. These agencies often seek input from organizations such as the American Conference of Governmental Industrial Hygienists (ACGIH) or the National Institutes of Health (NIOSH), which develop guidance values or recommendations based upon industrial experience assessing exposures and health outcomes. Occupational exposure limits are values that are expected to result in no adverse health outcomes if a worker is exposed 40 hours per week each year for a working career. Environmental exposure standards established by the EPA are intended to protect the entire population for 24 hours per day for a lifetime of exposure. Typically environmental exposure standards are more restrictive as they are established to ensure all members (even the ill, very young, and elderly) of the population will not suffer adverse health outcomes following continuous lifetime exposure.

Substantial data exist regarding the occupational and environmental exposure to diesel engine emissions as well as the acute and chronic health impacts associated with the pollutants to be targeted in this work. The project participants developed a summary database that compiles the critical target organ effects and carcinogenic and non-carcinogenic potency, or potency range, for inhalation exposure to acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and respirable particulate matter (summary sheets shown in Appendix B). This database was developed following review of the current information available from the peer-reviewed scientific literature, the Agency for Toxic Substances and Disease Registry, the ACGIH, various EPA Staff Papers or Criteria Documents, the Hazardous Substances Data Bank, the Integrated Risk Information System, and NIOSH. Comparing monitoring results with established occupational and environmental standards provides an initial assessment of the potential risk to workers and nearby residents associated with the exposures monitored during fieldwork.

When considering the non-cancer health impacts of diesel exhaust exposure,[6] the US EPA recently finalized a health-protective **reference concentration of 5 μg/m^3** for diesel particulate matter (DPM).[7] The MSHA has established an interim allowable occupational exposure standard[8] for diesel particulate matter of **400 μg/m^3**. This standard will drop to a final allowable exposure limit for this worker population of **160 μg/m^3** within five years. The OSHA has yet to adopt a standard for diesel exhaust particulate matter. However, OSHA has identified diesel exhaust as a compound of concern and is developing an action plan to reduce worker exposure to this hazard. NIOSH considers diesel exhaust a potential occupational carcinogen and, as such, recommends that occupational exposures be reduced to the **"lowest feasible concentration."** The ACGIH is considering a recommendation for diesel exhaust but has yet to establish one.

A challenge when assessing exposure to DPM is that diesel exposure is typically measured using a surrogate, such as quantification of elemental carbon and organic carbon as done in this study. The results of EC/OC analysis are presented in Appendix C. Other researchers have used mass balance and emissions inventory data to estimate the diesel particulate matter contribution to ambient fine particulate matter concentrations. These projects have estimated that DPM constitutes a minimum of six percent of the national total ambient inventory for $PM_{2.5}$, which can be measured directly. In urban areas (and very likely on the nonroad construction sites evaluated in this study) the percentage of DPM could range from 10 to 36 percent of the $PM_{2.5}$ mass.[9]

When considering the non-cancer health effects associated with exposure to $PM_{2.5}$ mass in general, the current **National Ambient Air Quality Standard of 65 μg/m^3 (24-hour)** established by the United State Environmental Protection Agency may used to compare integrated 24-hour exposures on or near project sites. When considering allowable occupational exposures for fine (respirable) particulate matter, not otherwise specified, the OSHA has established a **permissible exposure limit of 5000 μg/m^3** and the ACGIH has established a **threshold limit value of 3000 μg/m^3**. The MSHA **standard of 400 μg/m^3** may also be used.

When evaluating cancer effects, the US EPA has not yet determined a unit risk value for DPM, therefore carcinogenic risks associated with exposures at the concentrations measured on the four sites are not estimated here.

When considering the cancer effects of the gaseous pollutants measured in this study, the benchmarks used by the EPA reflect the assumption that there is no concentration below which there is no risk (e.g., no threshold). Concentrations, which are assumed to present a potential public health concern, are derived by estimating a risk concentration for humans from observed tumor incidence in animals. The approach typically incorporates the idea

[6] The established reference concentration is based upon demonstrated inflammatory and histopathological changes in the lung in numerous species following diesel exhaust exposure.
[7] United States Environmental Protection Agency, Health Assessment Document for Diesel Engine Exhaust, USEPA/600/8-90/057F, May 2002.
[8] This standard addressed exposures for underground metal and nonmetal miners.
[9] United States Environmental Protection Agency, Health Assessment Document for Diesel Engine Exhaust, USEPA/600/8-90/057F, May 2002.

of multiple steps in cancer development, but assumes that the transition from one step to the next is irreversible. This approach has been criticized for these assumptions and the conservative concentrations, which are calculated using this “linear multistage model” approach. The EPA has recently been revising its guidelines for carcinogen risk assessment guidelines. The revisions are meant to allow flexibility in presentation of carcinogen risk assessment. A benchmark concentration represents the atmospheric concentration of a pollutant above which there may be potential public health concerns. The benchmark values essentially serve as “yardsticks” to assess the potential threat to public health posed by a toxicant. These values represent the current state of scientific understanding about the health effects of the pollutants of concern.

One of the most significant challenges presented by this work is that exposure to diesel exhaust around nonroad HDD equipment sites results in exceedances of environmental exposure standards but not occupational standards. For pollutants such as particulate matter, not otherwise specified, this is a dilemma as an individual’s exposure would be acceptable by one agency and unacceptable by another. This is a significant future policy challenge for occupational and environmental health professionals.

Appendix A: Summary Testing Matrix[10]

Date	Location	In-Cabin Monitoring (3 - 5 pieces)	Upwind Site – Perimeter #1 (~300ft X 300 ft site)	Downwind Site – Perimeter #2 (~300ft X 300 ft site)
July 2002 *through* June 2003	Roadway Construction Keene, NH Forestry Operations Carmel, ME Building Construction New York City Agricultural Operations Brattleboro, VT Roadway Construction Manchester, NH	**EC/OC**[11] Respirable cyclone (PM_4) @ 4.2 liters/minute **$PM_{2.5}$**[12] $PM_{2.5}$ cyclone @ 3.5 liters/minute **Volatile Organic Compounds**[13] (Carbotrap X and Carboxen 1016 absorbent trap) @ 0.200 liters/minute **Carbonyls**[14] (DNPH with O_3 scrubber) @ 0.200 liters/minute	**EC/OC** Respirable cyclone (PM_4) @ 4.2 liters/minute **$PM_{2.5}$** $PM_{2.5}$ cyclone @ 3.5 liters/minute **Volatile Organic Compounds**[15] SUMMA Canister with 8-hr orifice **Carbonyls** (DNPH w/ O_3 scrubber) @ 0.200 liters/minute **Real Time Black Carbon** Aethelometer (PM_4) **Real Time $PM_{2.5}$** EPAM-5000 ($PM_{2.5}$ kit) Data Logging **Weather** Station Tracking temperature, relative humidity, wind speed/direction, and dew point	**EC/OC** Respirable cyclone (PM_4) @ 4.2 liters/minute **EC/OC** BGI PQ100 ($PM_{2.5}$) @ 16.7 liters/minute **$PM_{2.5}$** $PM_{2.5}$ cyclone @ 3.5 liters/minute **Volatile Organic Compounds** SUMMA Canister with 8-hr orifice **Carbonyls** (DNPH w/ O_3 scrubber) @ 0.200 liters/minute **Real Time Black Carbon** Aethelometer (PM_4) **Real Time $PM_{2.5}$** EPAM 5000 ($PM_{2.5}$ kit)

[10] For each location evaluated three days (8-9 hour samples each day). This figure summarizes the monitoring conducted each of the three days for each location.
[11] Elemental Carbon/Organic Carbon, NIOSH Method #5040
[12] Gravimetric Analyses for total particulate mass
[13] EPA Method TO-17
[14] EPA Method TO-11
[15] EPA Method TO-15

Samples were collected on nonroad heavy-duty diesel equipment operators and at the perimeter of each site using established federal methods and novel real-time monitoring strategies. Each site was defined as a square approximately 300' X 300'. Global positioning system (GPS) coordinates were taken for each site and are being used to integrate the movement of equipment within the site on site maps that will be provided in final reports developed under this project. Perimeter monitors were positioned at an upwind and downwind location on this site grid at the start of each monitoring day. Due to wind direction changes throughout the monitoring day, however, these sites are not consistently upwind or downwind sites, rather perimeter monitors. The wind speed and direction was monitored on site as well and are being integrated with real-time monitoring results and subjected to statistical analyses. Until these analyses are completed, data are presented as perimeter #1 (initial upwind site) and perimeter #2 (initial downwind site).

The"in-cabin" exposure measurements for three pieces of heavy-duty equipment at each site were expected to characterize high-end exposures. Perimeter monitoring samples were collected to characterize the near-field ambient air quality impact of worksite operations. Eight-hour average integrated personal and perimeter exposure monitoring was conducted to quantify exposure to carcinogenic compounds and respiratory irritants of concern (i.e., benzene, 1,3-butadiene, acetaldehyde, and formaldehyde) and for respirable particulate matter ($PM_{2.5}$) and diesel soot (PM_4). Real-time monitoring was also conducted, as detailed above, to quantify respirable particulate matter ($PM_{2.5}$), diesel soot (PM_4), and site weather conditions.

Appendix B: Health Effects Database Summary Sheets

Acetaldehyde **CAS: 75-07-0** **Chemical Formula:** CH3CHO

Molecular Weight	44
RfC	9x10-3 mg/m3
RfD	No Data
EPA Unit Cancer Risk Value 1 :1,000,000	5x10-4 mg/m3
Occupational Limits	
15 - minute STEL	none specified
OSHA PEL 8-hour TWA	200 ppm
ACGIH TLV	25ppm
NIOSH REL	carcinogen, lowest feasible
Ceiling	45 mg/m3 Ceiling- ACGIH Recommendation
NH State Ambient Air Limit	161=24-hour AAL http://www.des.state.nh.us/rules/env-a1400.pdf

Target Organs	**Type of effect in humans** NIOSH	**Type of effect in animals-RATS**
Eyes	Irritation eyes, eyes burning, Blurred vision.	
Skin	dermatitis, skin burning	squamous cell carcinomas
Respiratory System	Irritation-nose, throat, Shortness of breath.	Nasal Cancer, Male/Female Rats
Central Nervous System	Depression, Unconsciousness.	
Reproductive System		kidney, reproductive, teratogenic effects
Developmental		
Kidneys		
Potential Human Carcinogen	B2 Classification, Nasal in animals	

NOAEL	**LOAEL-**http://www.epa.gov/iris/subst/0290.htm#carc	**LC50**http://www.hhmi.org/research/labsafe/lcss/lcss.html OR *http://epa.gov/ttn/atw/hlthef/acetalde.html*
Rat-150ppm or 48.75 mg/cu.m	Rat-16.9 mg/cu.m-adenocarcinomas from olfactory epithelium	Rat-20,550 ppm inhalation/37,000mg/m3 Rat inhalation

Sampling Methods OSHA	**Primary**
Method No.	2(OSHA 68)
Media:	Coated XAD-2 Tube (450/225 mg sections, 20/60 mesh) Coating is 10% (w/w) 2-(Hydroxymethyl)piperidine.
ANL Solvent:	Toluene
Max Volume (TWA)	3 liters
Max Flow (TWA)	0.05 L/min
Max Volume (STEL)	0.75 L
Max Flow (STEL)	0.05 L/min
ANL 1:	Gas Chromatography
SAE	0.1
Class	Fully Validated

Benzene **CAS: 71-43-2** **Chemical Formula:** C_6H_6

Molecular Weight	78
RfC	RfC of 9 E-3 mg/m^3 http://www.epa.gov/nceawww1/pdfs/benzene/benztox.htm
RfD	
EPA Unit Cancer Risk Value 1 :1,000,000	1.3x 10-4 or 4.5x10-4 mg/m^3
Occupational Limits	
15 - minute STEL	5 ppm
OSHA PEL 8-hour TWA	1 ppm (Action Level-.5 ppm)
ACGIH TLV	0.5 ppm
NIOSH REL	0.1 ppm
Ceiling	25 ppm
NH State Ambient Air Limit	5.714 = 24-hour AAL http://www.des.state.nh.us/rules/env-a1400.pdf

Target Organs-NIOSH	**Type of effect in humans**	**Type of effect in animals**
Eyes	Contact of vapor- Irritating, Contact with liquid- irritation, pain;prolonged cause tissue damage	
Skin	Irritation, Redness, Repeated exposure, dermatitus, removes oil from skin, dryness	squamous cell carcinomas
Respiratory System	cough, hoarseness, general irritation of nose, throat and resp. tract	
Blood	cause anemia, leukemia, Hodgkin's Disease	leukemia
Central Nervous System	Drowsiness, headache, nausea, incoordination	
Bone Marrow	Decrease in production or changes to the cells of hemoglobin, hematocrit, red/white blood cells	reduced the cellularity of the bone marrow
Reproductive		
Developmental		
potential occupational carcinogen	Leukemia	

NOAELwww.atsdr.com	**LOAEL**www.atsdr.com	**LC50** www.atsdr.com/EPA http://www.epa.gov/ttnatw01/urban/natpapp.pdf
Item # 65=10 ppm Rat	Item # 11=Rat-47ppm (decreased maternal weight gain)	LC50 Mouse ihl 9980 ppm EPA= 31,887 mg/m3
Item # 31, 50=3 ppm Mouse	Item # 68=Mouse-9.6ppm (increased spleen weight)	LC50 Rat ihl 10,000ppm/7 hr EPA= 31,951 mg/m3
	Item # 14=Mouse-47ppm (decreased WBC Count)	
	Item# 85=Rat-88ppm (leukpenia)	
	Item #131=Rat-960ppm (30% depression of evoked electricalm activity)	
	Item # 135=Rat- 6,600ppm (testicular weight increase)	
	Item #140=Rat- 200ppm (CEL:hepatomes)	
	Item # 178=Rat- 100ppm (Liver tumors)	

Sampling Methods OSHA	**Primary**
Method No.	2 (OSHA 1005)
Media:	Charcoal Tube (100/50 mg sections, 20/40 mesh)
ANL Solvent:	Carbon Disulfide
ALT Solvent:	(99:1) Carbon Disulfide/Dimethylformamide
Max Volume (TWA)	12 Liters
Max Flow (TWA)	0.05 L/min (TWA)
Max Volume (STEL)	0.75 Liters
Max Flow (STEL)	0.05 L/min (STEL)
ANL 1:	Gas Chromatography;GC/FID
SAE	none specified
Class	Fully Validated

1,3 - Butadiene

CAS: 106-99-0

Chemical Formula:

Molecular Weight	54
RfC	2 × 10-3; mg/m^3 http://www.epa.gov/iris/subst/0139.htm#top
RfD	No Data
EPA Unit Cancer Risk Value 1 :1,000,000	2.1x10-6 µg/m3
Occupational Limits	
15 - minute STEL	5 ppm
OSHA PEL 8-hour TWA	1 ppm (Action level- .5ppm)
ACGIH TLV	2 ppm, 4.4 mg/m3 TWA
NIOSH REL	Lowest Feasible Concentration
Ceiling	None Specified
NH State Ambient Air Limit	16=24-hour AAL http://www.des.state.nh.us/rules/env-a1400.pdf

Target Organs-NIOSH	**Type of effect in humans**	**Type of effect in animals(MICE)**
Eyes	Irritation eyes, Blurred Vision	
Central Nervous System	Drowsiness, headache, fatigue	CNS Depression
Respiratory System	Irritation Nose, Dryness Irritation, respiratory paralysis	bronchiolar adenomas, neoplasms
Reproductive System	Teratogenic Reproductive Effects	granulosa cell tumors,(females) acinar cell carcinomas of mammary gland, testicular atrophy
Skin (liquid exposure)	Frostbite, Irritation	
Reproductive		
Developmental		
potential occupational carcinogen	Hematopoetic Cancer	

NOAELwww.atsdr.com	**LOAEL**www.atsdr.com	**LC50** www.atsdr.com/ EPA http://www.epa.gov/ttnatw01/urban/natpapp.pdf
Item # 7=200ppm Rat	Item # 7=Rat- 1000 ppm (wavy ribs)	LC50 Rat inhalation 285,000 mg/cu m/4 hr EPA=269,896 mg/m3
Item # 22= 6.25 ppm- Mice	Item # 22= Mouse- 20ppm (Increased Mortality)	LC50 Mouse inhalation 270,000 mg/cu m/2 hr EPA= 285,382 mg/m3

Sampling Methods OSHA	**Primary**
Method No.	2 (OSHA 56)
Media:	Coated Charcoal Tube (100/50 mg sections, 20/40 mesh); Coating is 10% (w/w) 4-t-Butylcatechol.
ANL Solvent:	Carbon Disulfide
Max Volume (TWA)	3 Liter
Max Flow (TWA)	0.05 L/min (TWA & STEL)
Max Volume (STEL)	
Max Flow (STEL)	
ANL 1:	Gas Chromatography; GC/FID
SAE	0.11
Class	Fully Validated

Formaldehyde **CAS: 50-00-0** **Chemical Formula:** CH_2O

Molecular Weight	30
RfC	no data
RfD	2E-1 mg/kg/day
EPA Unit Cancer Risk Value 1 :1,000,000	8E-2 ug/m^3
Occupational Limits	
15 - minute STEL	2ppm
OSHA PEL 8-hour TWA	0.75ppm (action level-0.5ppm)
ACGIH TLV	0.3ppm
NIOSH REL	0.016ppm
Ceiling	0.3 ppm ceiling (ACGIH)
NH State Ambient Air Limit	1.321=24-hour AAL http://www.des.state.nh.us/rules/env-a1400.pdf

Target Organs-NIOSH	**Type of effect in humans**	**Type of effect in animals(MICE)**
Eyes	Irritation eyes, Blurred Vision	
Respiratory System	Irritation nose, throat, respiratory system; lacrimation (discharge of tears); cough; wheezing	
potential occupational carcinogen	nasal cancer	

NOAEL-http://www.epa.gov/iris/subst/0419.htm#refinhal	**LOAEL-**http://www.epa.gov/iris/subst/0419.htm#refinhal	**LC50** http://www.jtbaker.com/msds/englishhtml/F5522.htm
15 mg/kg/day (male rat) Reduced weight gain, histopathology in rats	82 mg/kg/day (rat) 2 year Bioassay	LC50 Rat inhalation 203 mg/m3 LC50: 64000 ppm/4H
	0.2 (nasal irritation) Human (atsdr.cdc.gov)	
	2ppm (eye irritation) Rat (atsdr.cdc.gov)	

Sampling Methods OSHA	**Primary**
Method No.	OSHA 52
Media:	sampling tubes containing XAD-2 adsorbent which has been coated with 2-(hydroxymethyl)piperidine.
ANL Solvent:	desorbed with toluene
Max Volume (TWA)	24 L
Max Flow (TWA)	0.1 L/min
Max Volume (STEL)	3 L
Max Flow (STEL)	0.2 L/min
ANL 1:	GC w/ nitrogen phosphorus flame ionization detector.
Class	Evaluated method

Diesel Exhaust

CAS: none

Molecular Weight	Not available
RfC	5µg/m³
RfD	Not available
EPA Unit Cancer Risk Value 1 :1,000,000	diesel exhaust (DE) is likely to be carcinogenic to humans
Occupational Limits	
15 - minute STEL	none
OSHA PEL 8-hour TWA	none
ACGIH TLV	none
NIOSH REL	lowest feasible
Ceiling	none
NH State Ambient Air Limit	24-hour AAL http://www.des.state.nh.us/rules/env-a1400.pdf

Target Organs	**Type of effect in humans** NIOSH
Eyes	Irritation eyes, slight redness
Respiratory System	pulmonary function changes; [potential occupational carcinogen]
Central Nervous System	neurophysiological symptoms, lightheadedness, nausea
Potential Human Carcinogen	not available

NOAEL	**LOAEL-**http://www.epa.gov/iris/subst/0642.htm#carc
Rat chronic inhalation study Ishinishi et al. (1988) NOAEL: 0.46 mg/m³ NOAEL/HEC: 0.144 mg DPM/m³	0.96 Ishinishi *et al.* (1988) (HD)

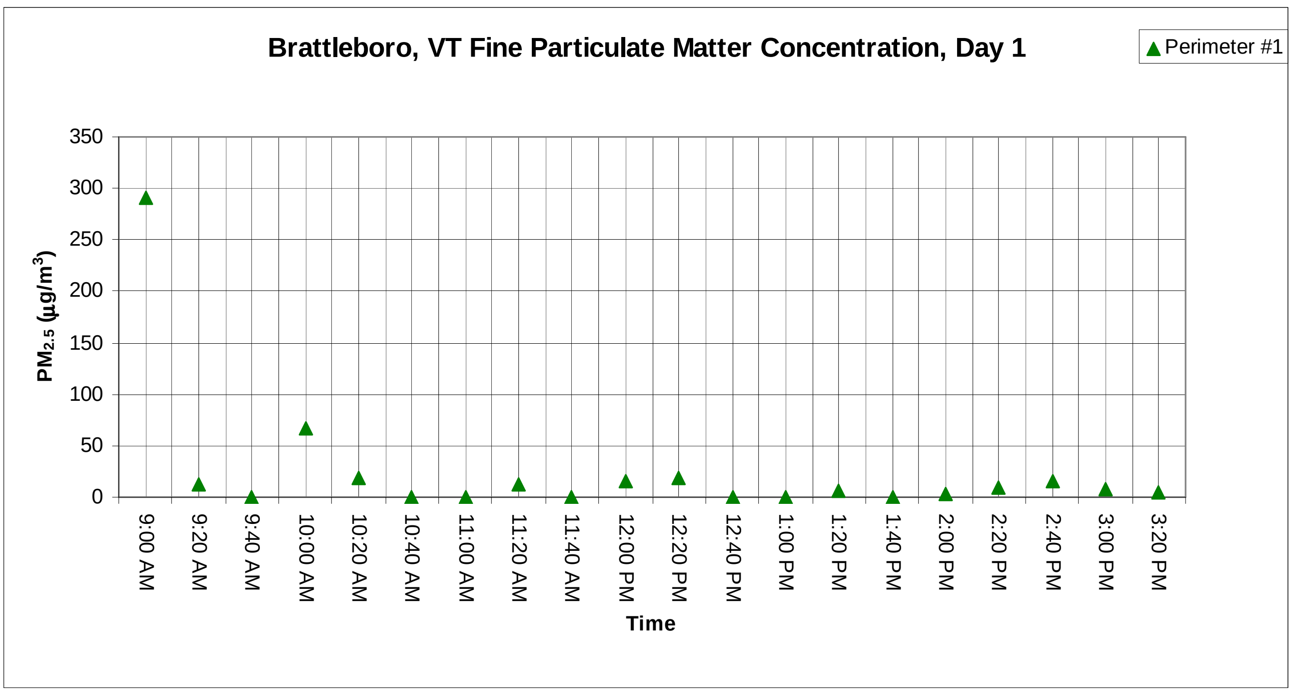
Sampling Methods OSHA	**Primary**
Method No.	ID-196 (Carbon Black in Workplace Atmospheres)
Media:	Samples are collected on polyvinyl chloride (PVC) filters. 37mm. 5.0-micrometer pore size
Max Volume (TWA)	480 to 960 liters
Max Flow (TWA)	2 liters/minute
ANL 1:	gravimetric
CLASS	Fully Validated

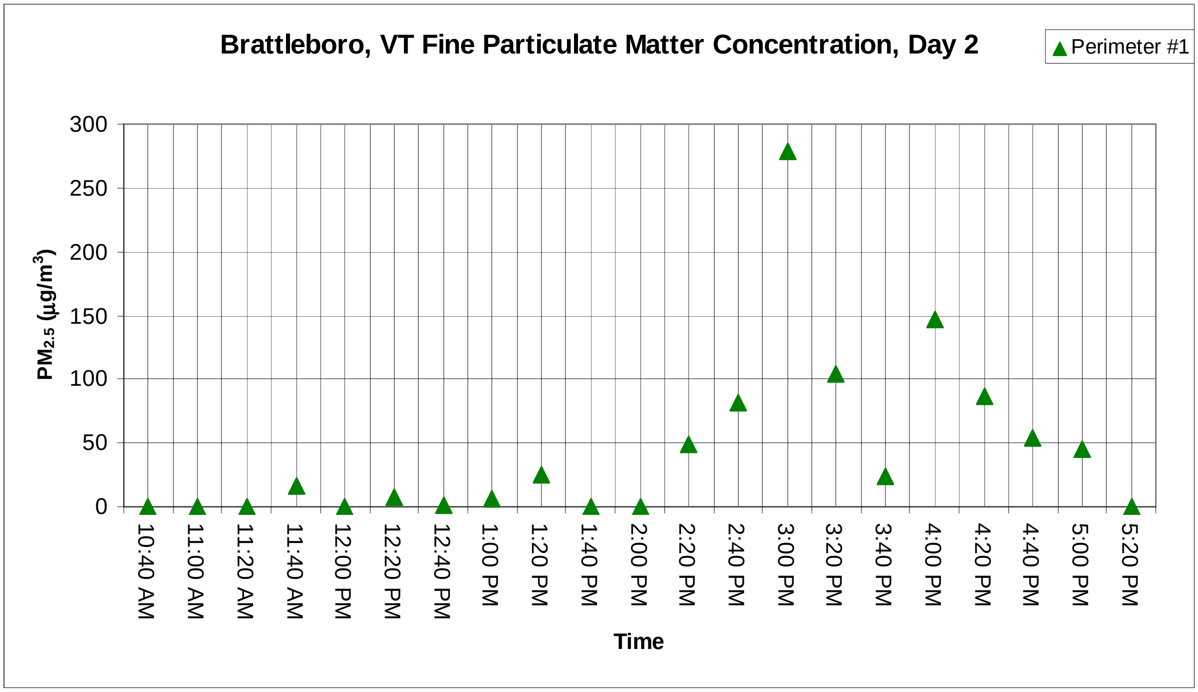
Appendix C: Monitoring Results All Sites By Pollutant

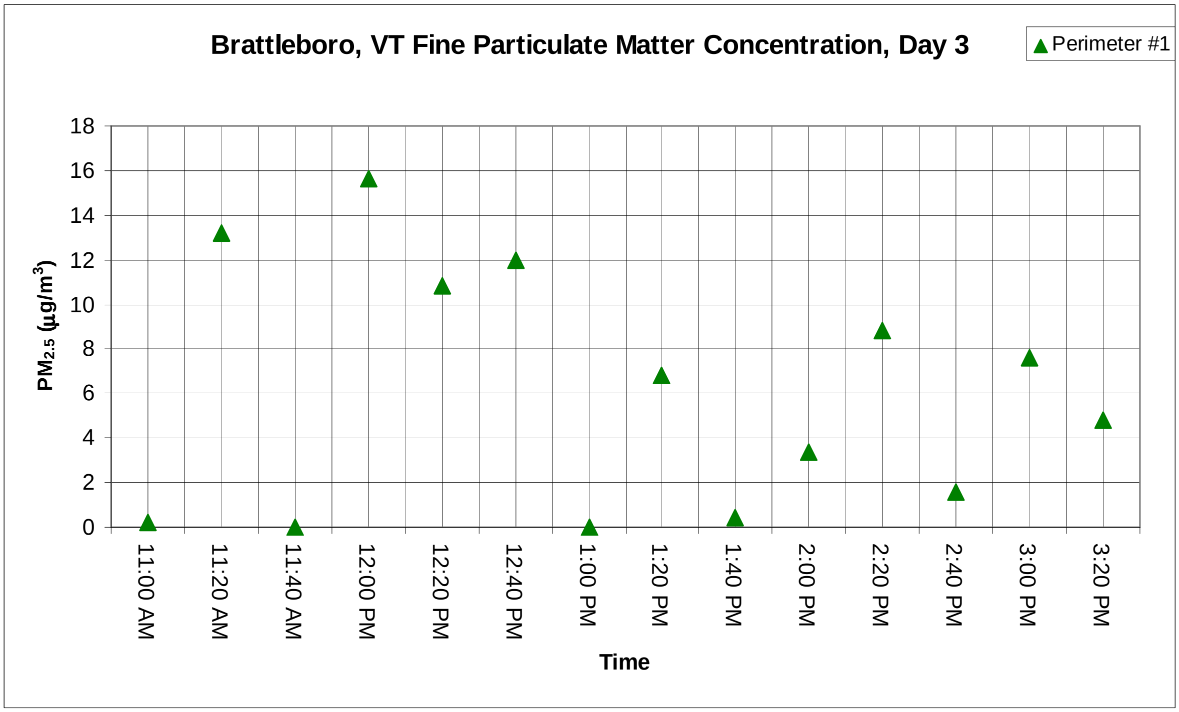
Daily Minute-to-Minute Exposure $PM_{2.5}$:

The peak concentrations observed during very active work may present *acute* health risks for workers and nearby residents as shown in the following figures for each site. Note the wide differences in concentration between the Maine Lumberyard and the New York City Construction site. Future analyses will identify specific instances of potential adverse acute exposure health effects and variability between sites.

Real-time $PM_{2.5}$ concentrations at the perimeter of nonroad equipment sites.




Brattleboro, VT Fine Particulate Matter Concentration, Day 2
Perimeter #1
300
250
200
150
100
50
0
PM2.5 (µg/m3)
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
2:00 PM
2:20 PM
2:40 PM
3:00 PM
3:20 PM
3:40 PM
4:00 PM
4:20 PM
4:40 PM
5:00 PM
5:20 PM
Time


Brattleboro, VT Fine Particulate Matter Concentration, Day 3
Perimeter #1
18
16
14
12
10
8
6
4
2
0
PM2.5 (µg/m3)
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
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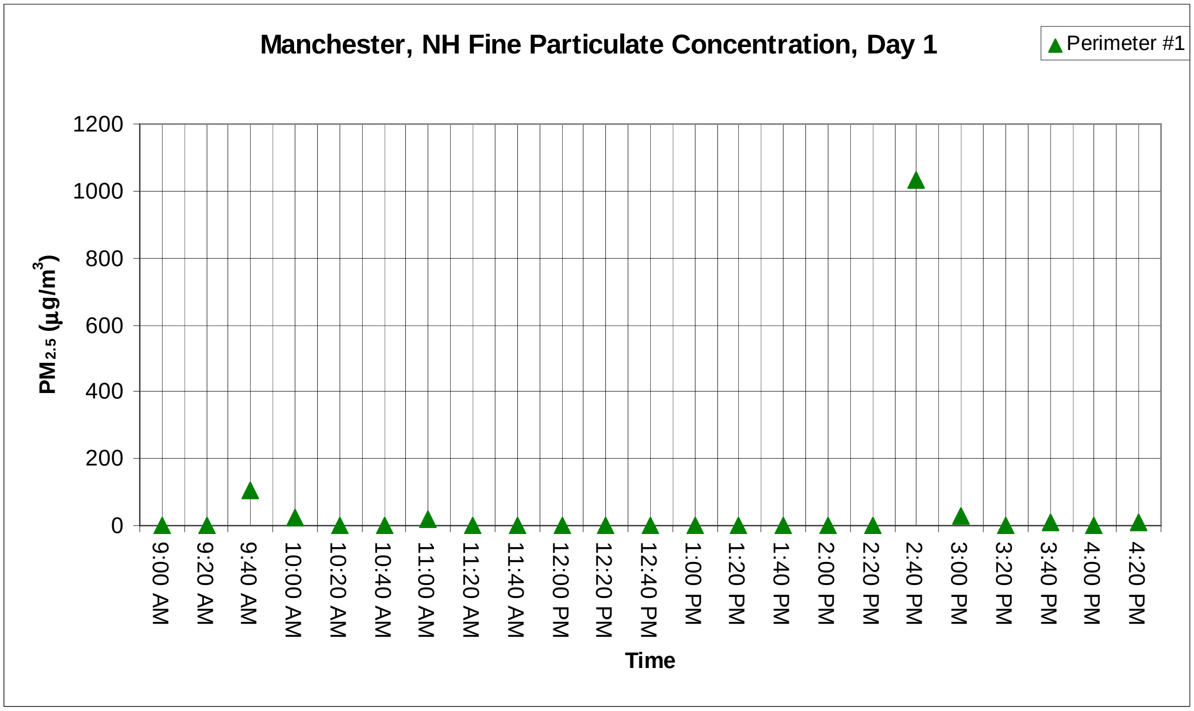
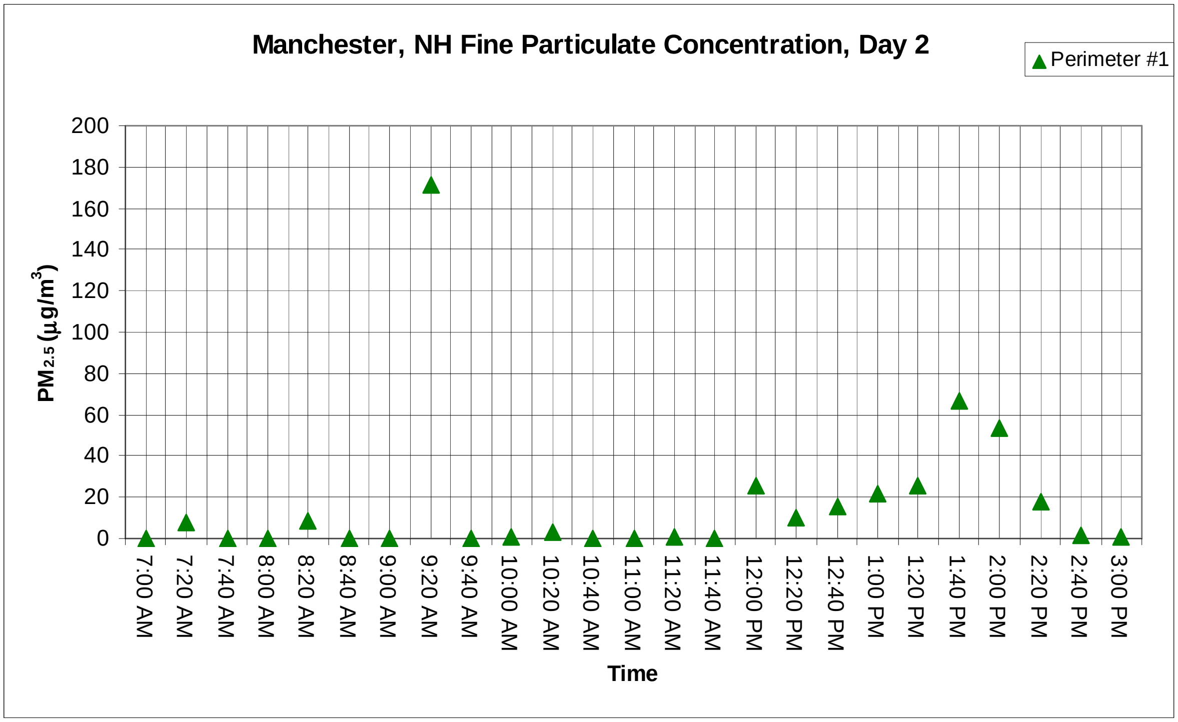
1:40 PM
2:00 PM
2:20 PM
2:40 PM
3:00 PM
3:20 PM
Time


Manchester, NH Fine Particulate Concentration, Day 1
Perimeter #1
PM2.5 (µg/m3)
1200
1000
800
600
400
200
0
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
2:00 PM
2:20 PM
2:40 PM
3:00 PM
3:20 PM
3:40 PM
4:00 PM
4:20 PM
Time


Manchester, NH Fine Particulate Concentration, Day 2
Perimeter #1
PM2.5 (µg/m3)
200
180
160
140
120
100
80
60
40
20
0
7:00 AM
7:20 AM
7:40 AM
8:00 AM
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
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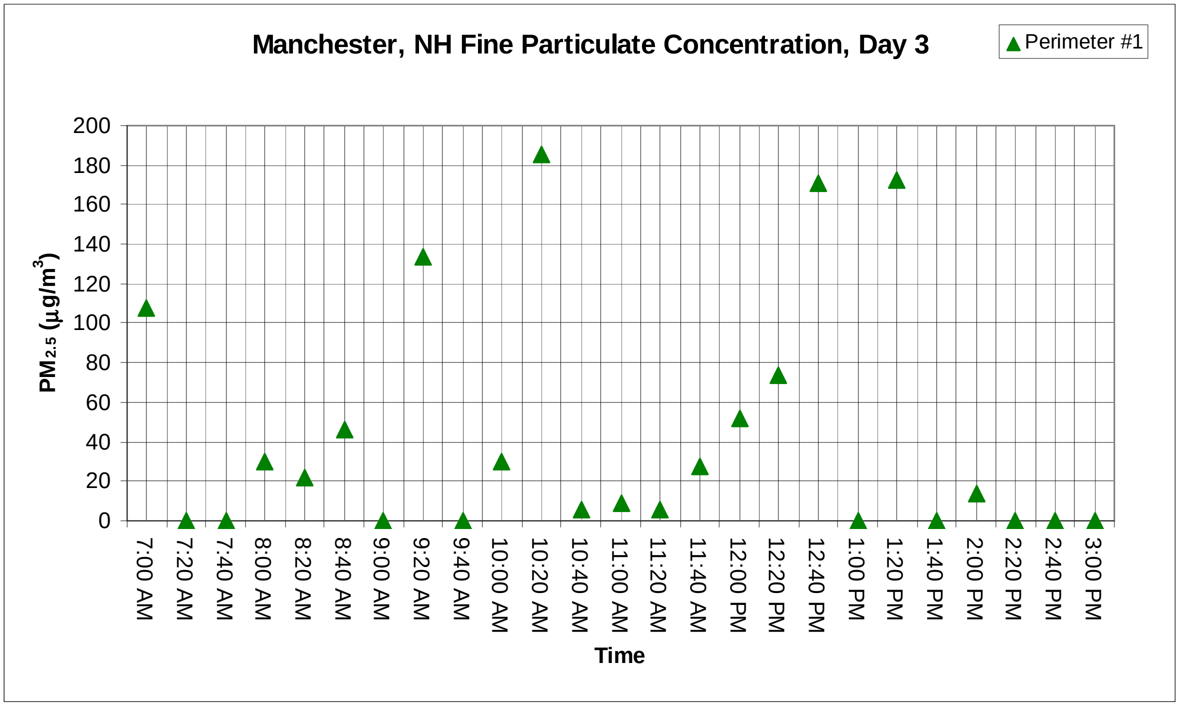
1:00 PM
1:20 PM
1:40 PM
2:00 PM
2:20 PM
2:40 PM
3:00 PM
Time


Manchester, NH Fine Particulate Concentration, Day 3
Perimeter #1
PM2.5 (µg/m3)
200
180
160
140
120
100
80
60
40
20
0
7:00 AM
7:20 AM
7:40 AM
8:00 AM
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
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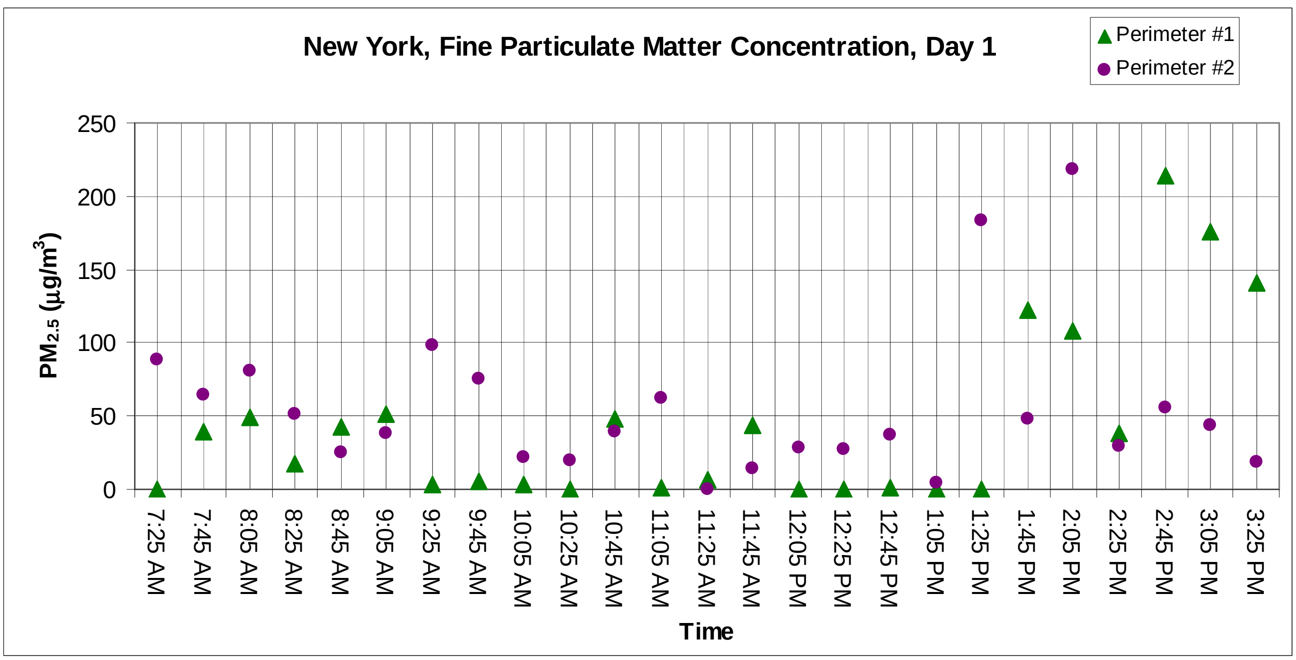
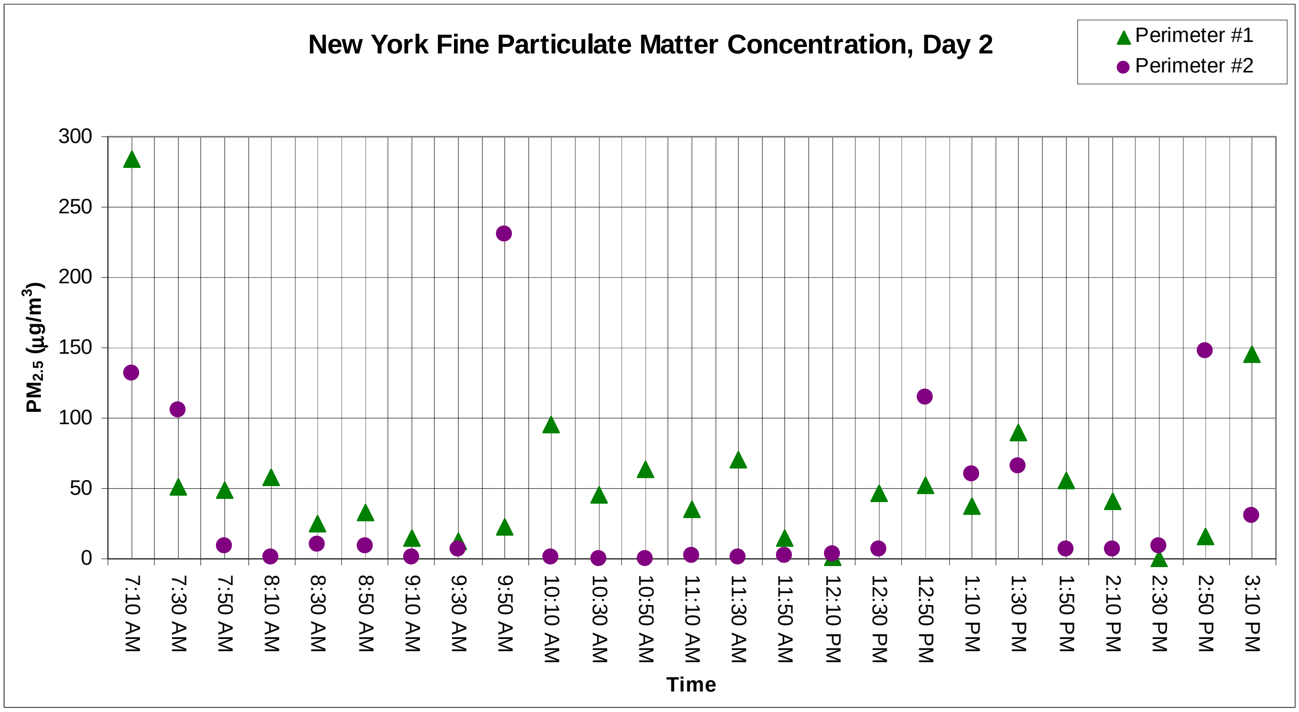
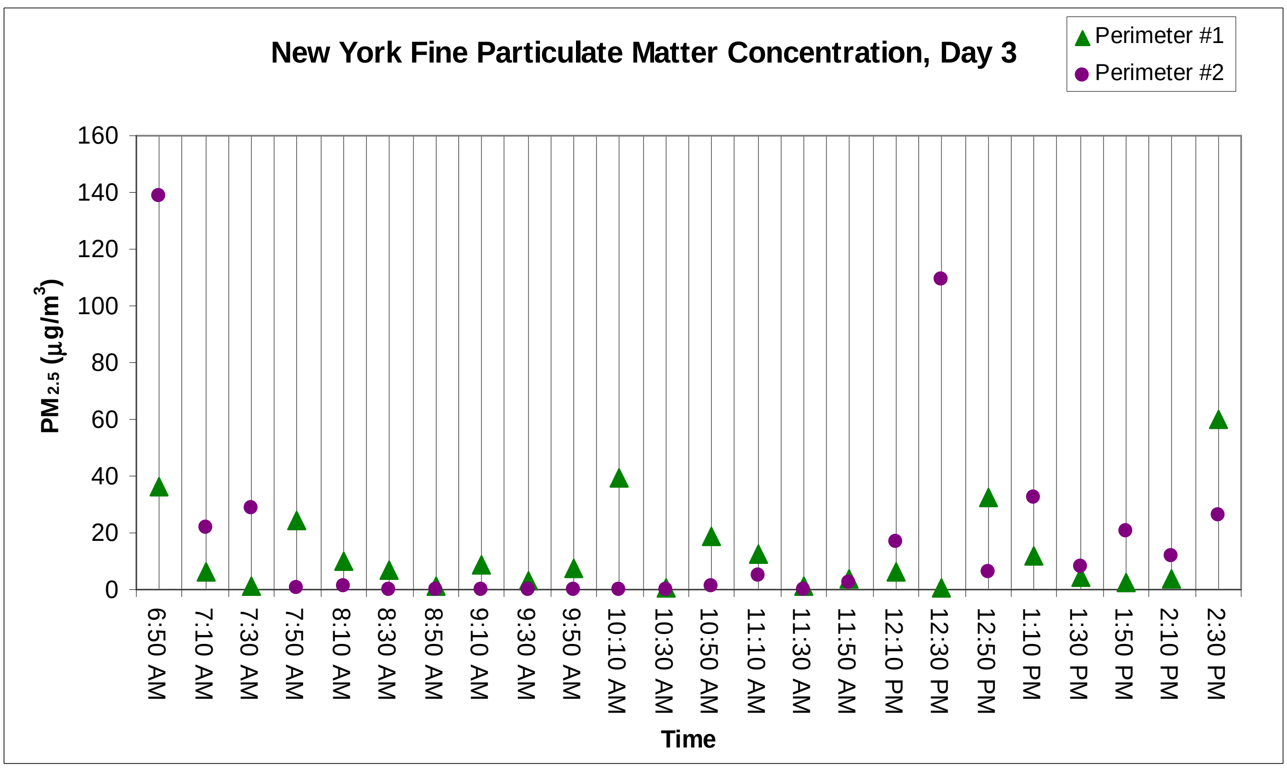
1:00 PM
1:20 PM
1:40 PM
2:00 PM
2:20 PM
2:40 PM
3:00 PM
Time

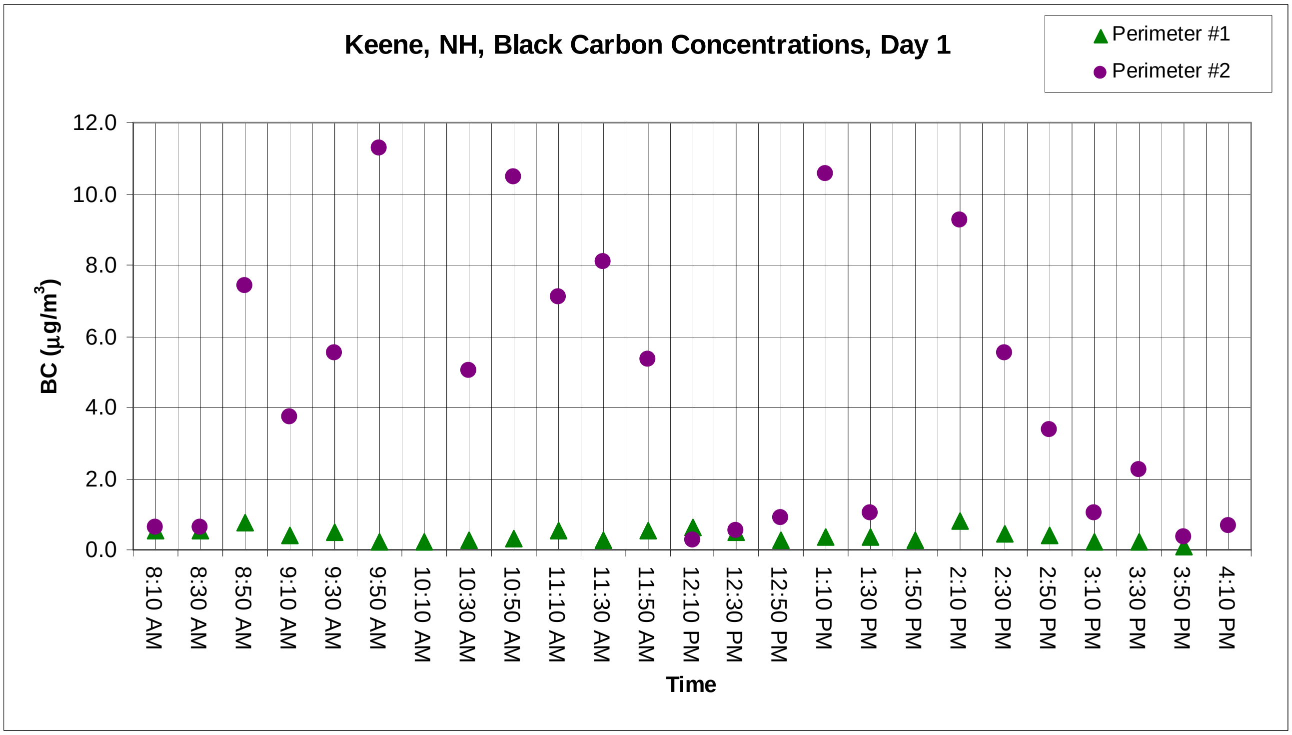

New York, Fine Particulate Matter Concentration, Day 1
Perimeter #1
Perimeter #2
PM2.5 (µg/m3)
250
200
150
100
50
0
7:25 AM
7:45 AM
8:05 AM
8:25 AM
8:45 AM
9:05 AM
9:25 AM
9:45 AM
10:05 AM
10:25 AM
10:45 AM
11:05 AM
11:25 AM
11:45 AM
12:05 PM
12:25 PM
12:45 PM
1:05 PM
1:25 PM
1:45 PM
2:05 PM
2:25 PM
2:45 PM
3:05 PM
3:25 PM
Time

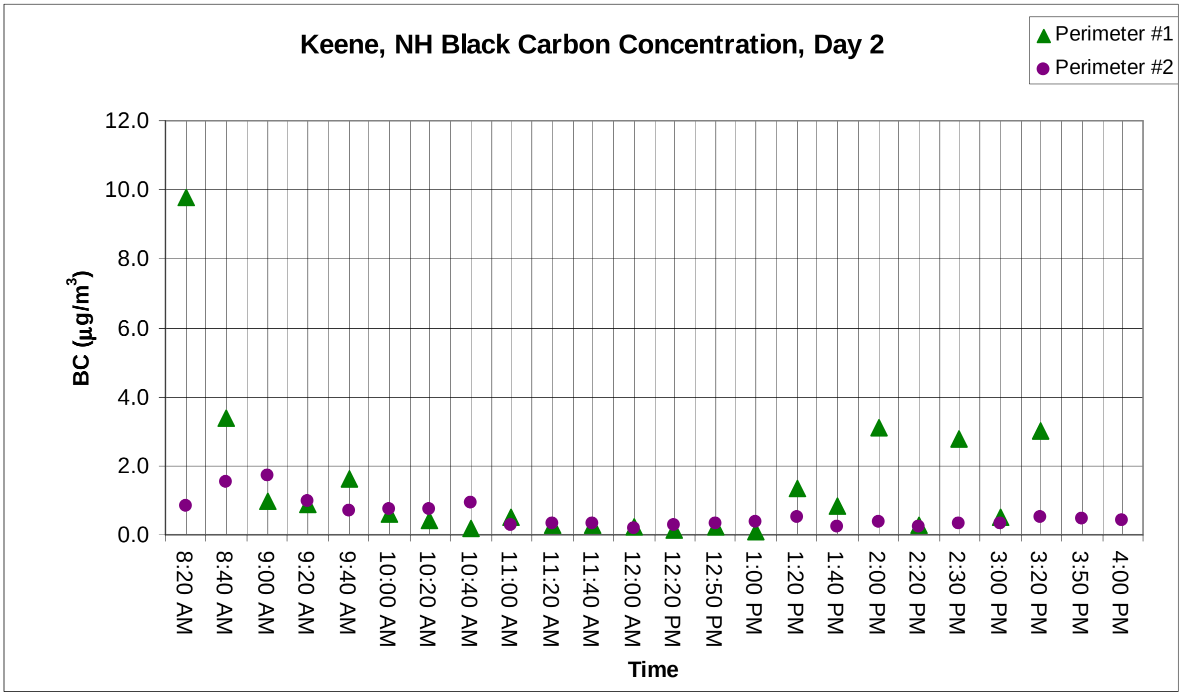

New York Fine Particulate Matter Concentration, Day 2
Perimeter #1
Perimeter #2
PM2.5 (µg/m3)
300
250
200
150
100
50
0
7:10 AM
7:30 AM
7:50 AM
8:10 AM
8:30 AM
8:50 AM
9:10 AM
9:30 AM
9:50 AM
10:10 AM
10:30 AM
10:50 AM
11:10 AM
11:30 AM
11:50 AM
12:10 PM
12:30 PM
12:50 PM
1:10 PM
1:30 PM
1:50 PM
2:10 PM
2:30 PM
2:50 PM
3:10 PM
Time


New York Fine Particulate Matter Concentration, Day 3
Perimeter #1
Perimeter #2
PM2.5 (µg/m3)
160
140
120
100
80
60
40
20
0
6:50 AM
7:10 AM
7:30 AM
7:50 AM
8:10 AM
8:30 AM
8:50 AM
9:10 AM
9:30 AM
9:50 AM
10:10 AM
10:30 AM
10:50 AM
11:10 AM
11:30 AM
11:50 AM
12:10 PM
12:30 PM
12:50 PM
1:10 PM
1:30 PM
1:50 PM
2:10 PM
2:30 PM
Time

Daily Minute-to-Minute Exposure Diesel Particulate Matter (Diesel Soot-Black Carbon) and Average Diesel Particulate Matter Exposure (Elemental Carbon) :

As shown in the following figures, diesel soot concentrations (measured as black carbon –BC, by aethelometers) vary throughout the day, anticipated to be due to nonroad equipment activity on the site. Additionally, daily average elemental carbon concentrations (as measured as elemental carbon – EC using filter sampling and NIOSH method 5040) are shown to be elevated at all sites evaluated and to vary between sites. Future analyses will compare these results to observations recorded in the time-activity diaries for each site. Note the vast difference, as shown in the previous fine particulate matter figures, between the urban and rural sites monitored in this study. Recalling that the reference concentration for diesel particulate matter is **5 μg/m^3**, it is possible to identify daily overexposures either by calculating the average BC concentration for the monitoring day or by evaluating the daily average EC concentration.





Keene, NH Black Carbon Concentration, Day 2
Perimeter #1
Perimeter #2
BC (µg/m3)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 AM
12:20 PM
12:50 PM
1:00 PM
1:20 PM
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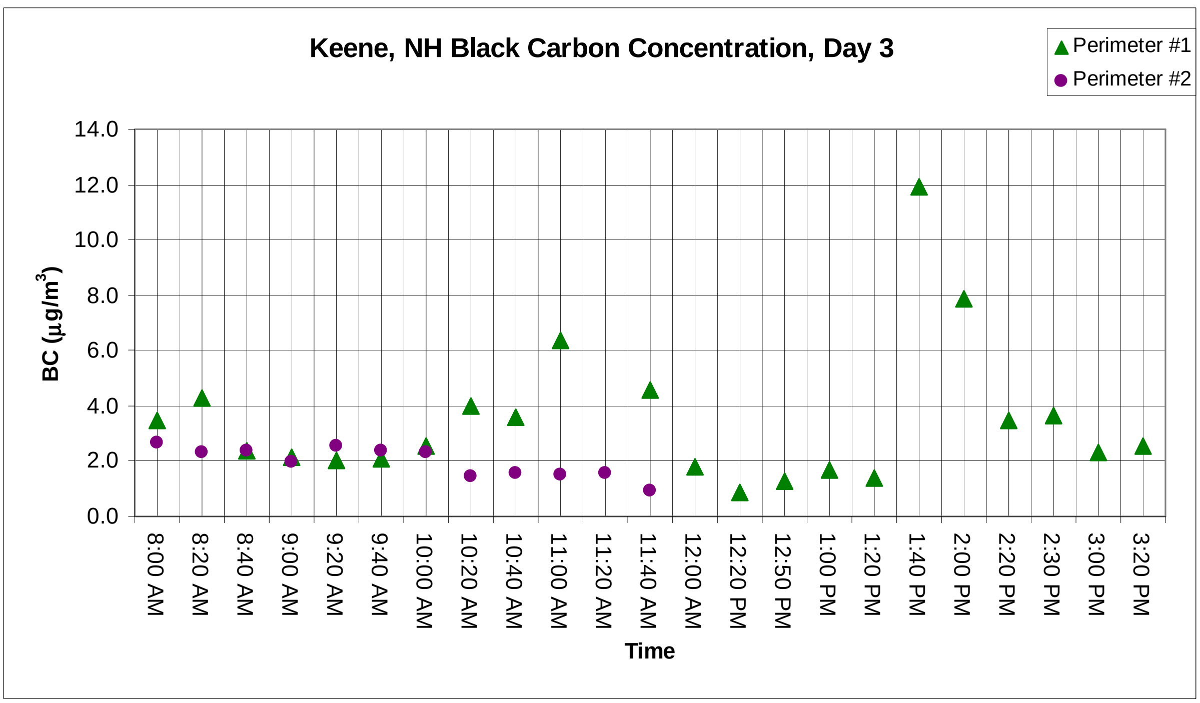
2:00 PM
2:20 PM
2:30 PM
3:00 PM
3:20 PM
3:50 PM
4:00 PM
Time



Keene, NH Black Carbon Concentration, Day 3
Perimeter #1
Perimeter #2
BC (µg/m3)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
8:00 AM
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 AM
12:20 PM
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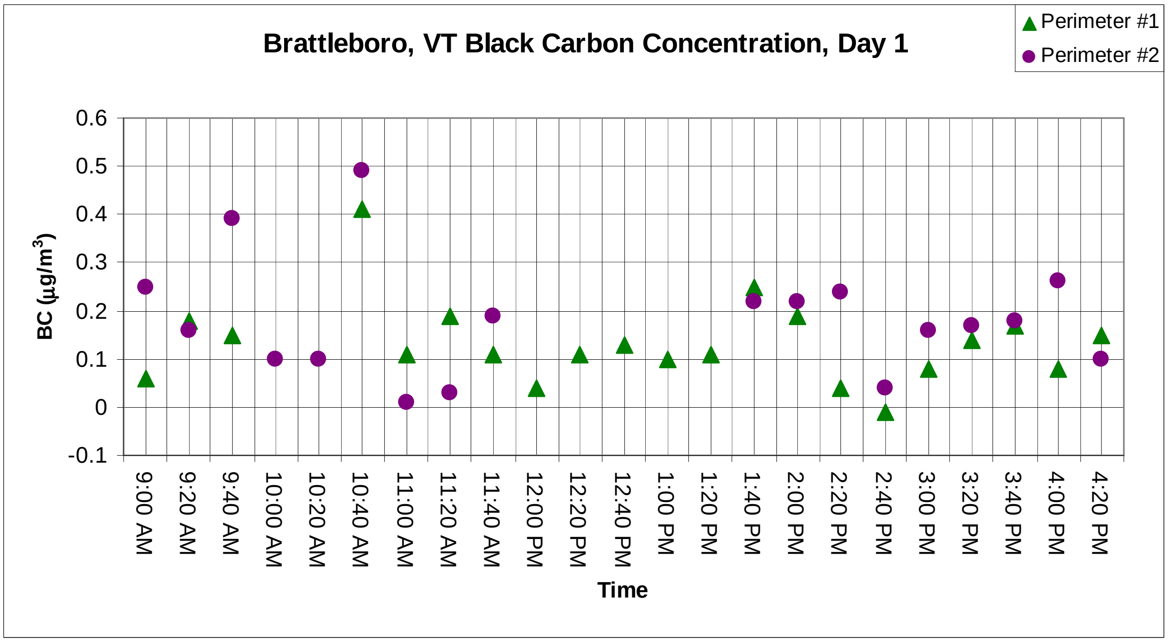
2:30 PM
3:00 PM
3:20 PM
Time


Brattleboro, VT Black Carbon Concentration, Day 1
Perimeter #1
Perimeter #2
BC (µg/m3)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
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2:40 PM
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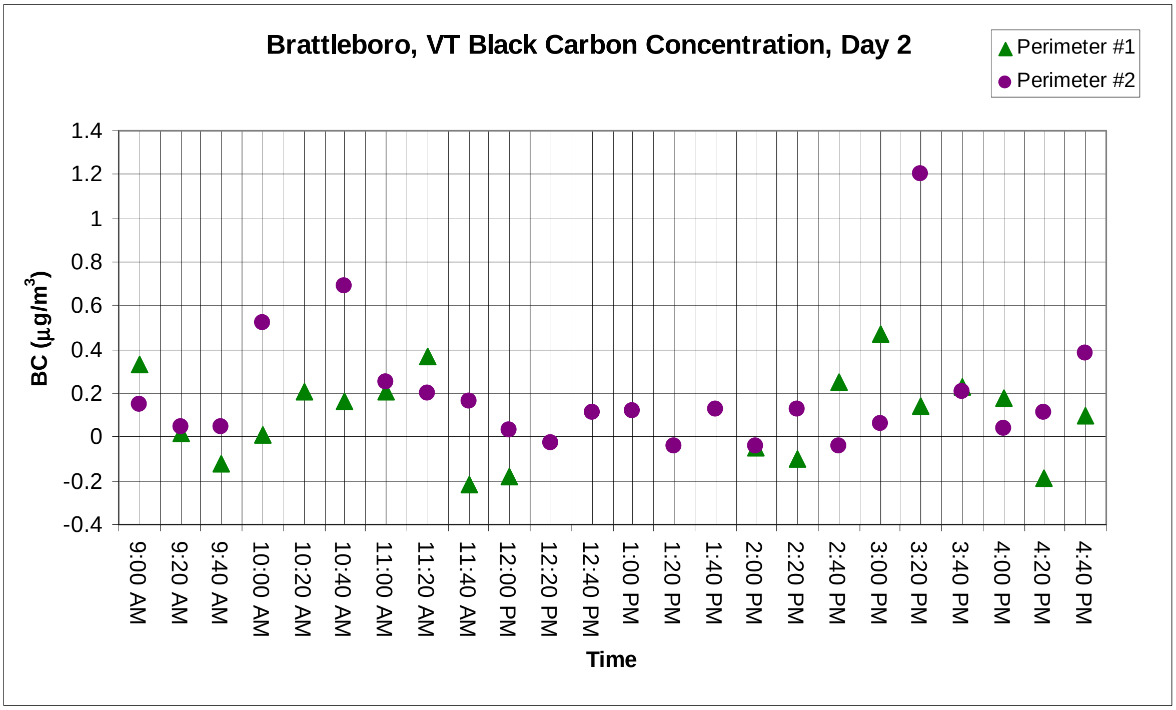
4:00 PM
4:20 PM
Time


Brattleboro, VT Black Carbon Concentration, Day 2
Perimeter #1
Perimeter #2
BC (µg/m3)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
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3:20 PM
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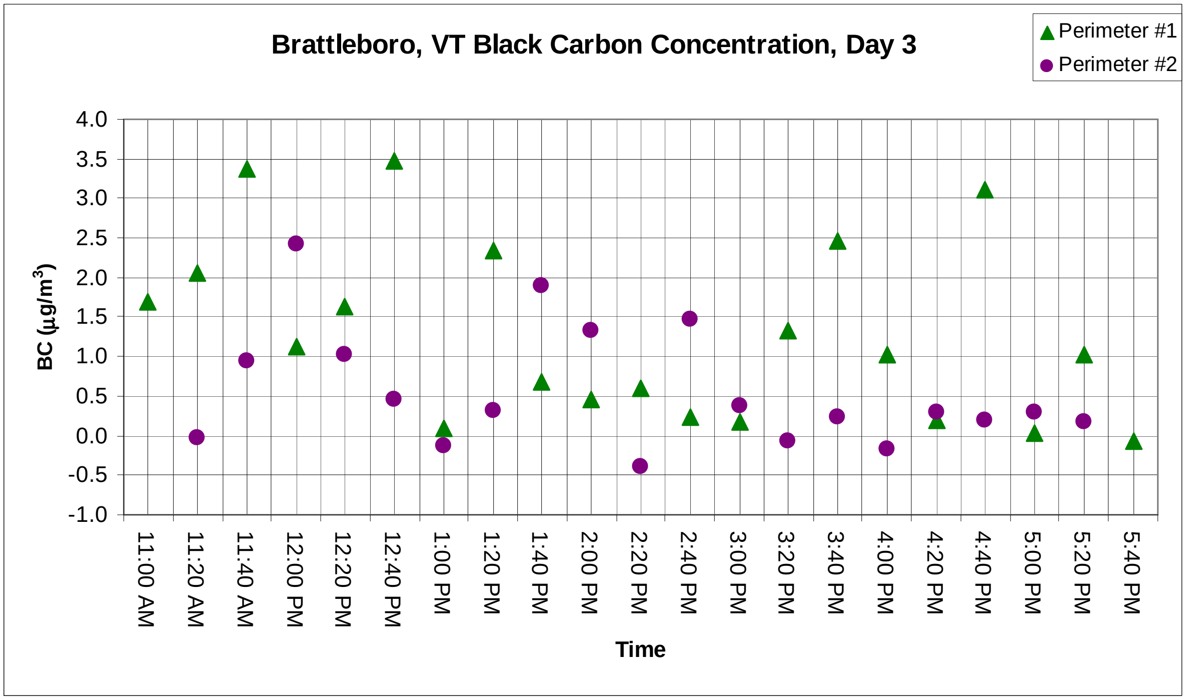
4:20 PM
4:40 PM
Time


Brattleboro, VT Black Carbon Concentration, Day 3
Perimeter #1
Perimeter #2
BC (µg/m3)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
2:00 PM
2:20 PM
2:40 PM
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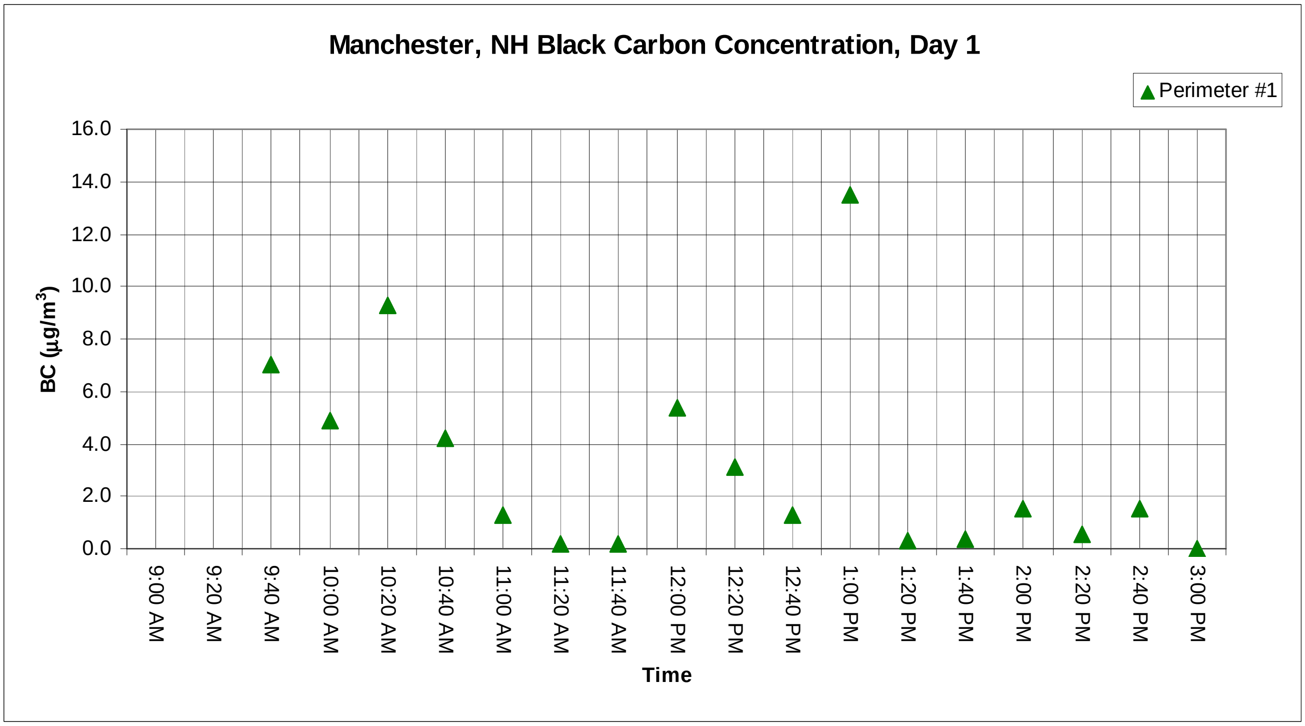
5:20 PM
5:40 PM
Time


Manchester, NH Black Carbon Concentration, Day 1
Perimeter #1
BC (µg/m3)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
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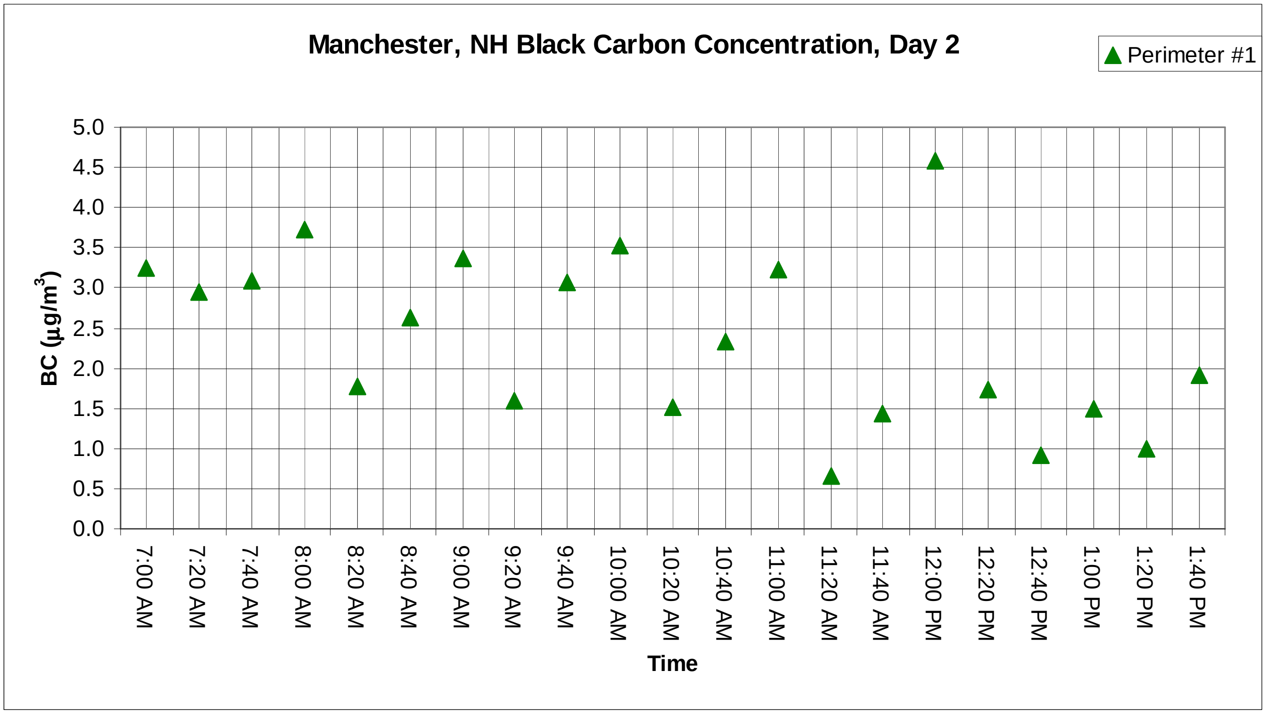
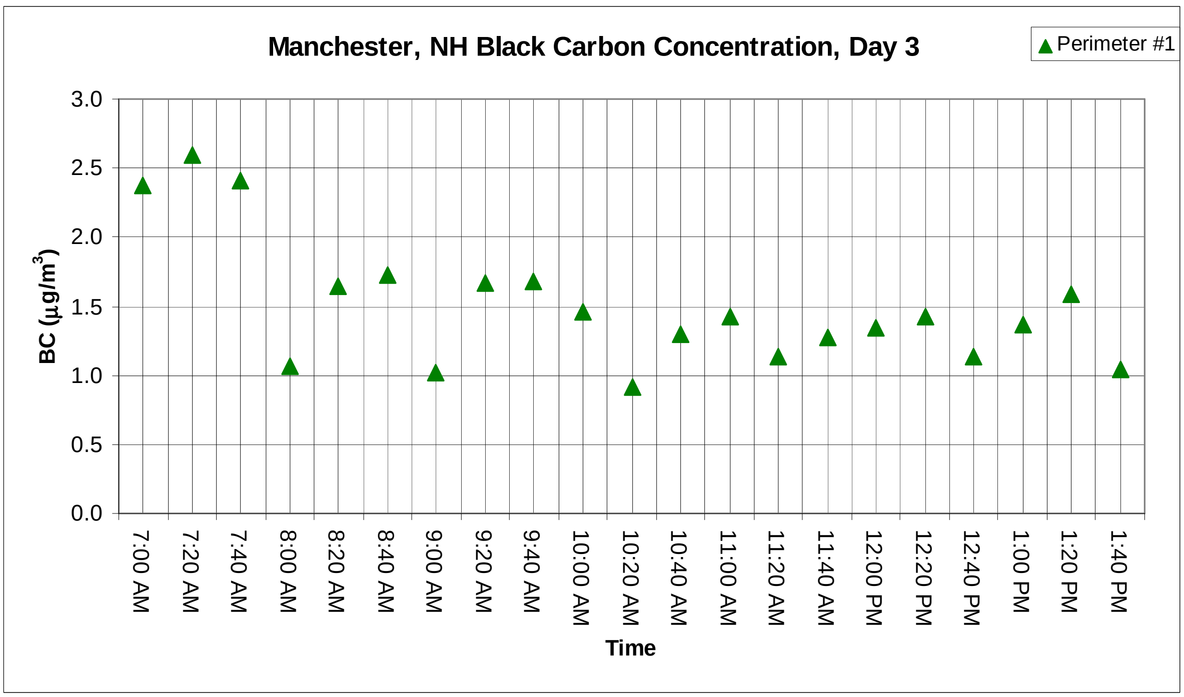
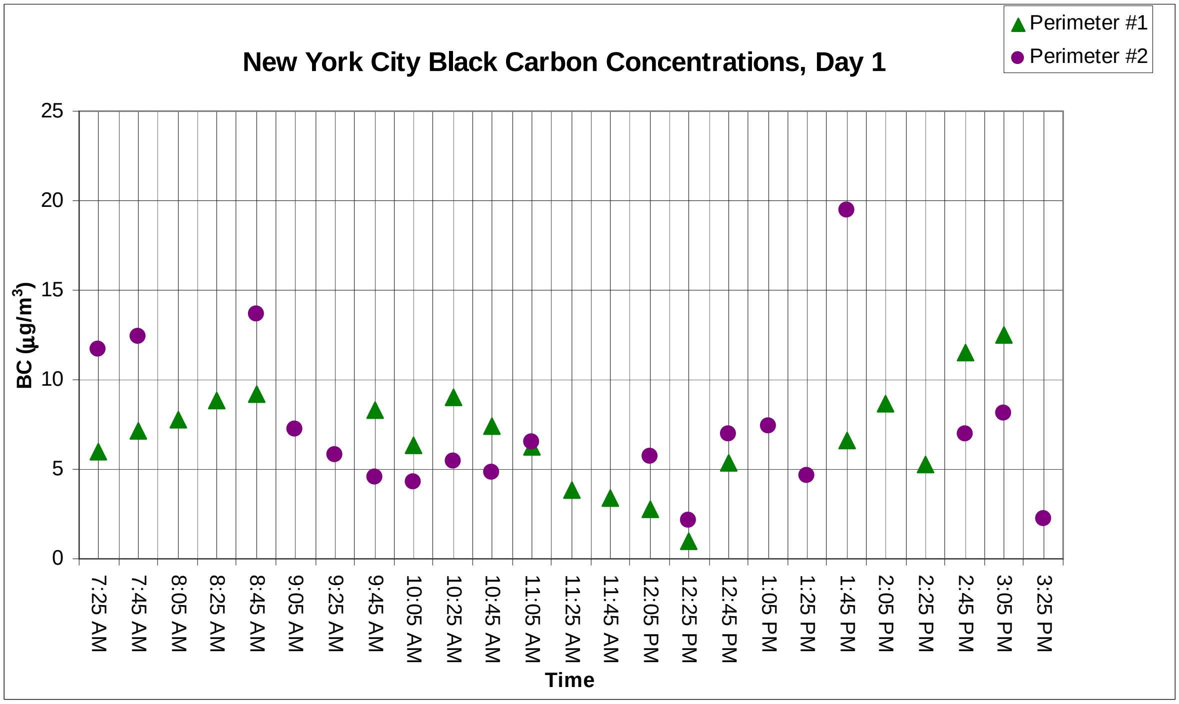
2:20 PM
2:40 PM
3:00 PM
Time

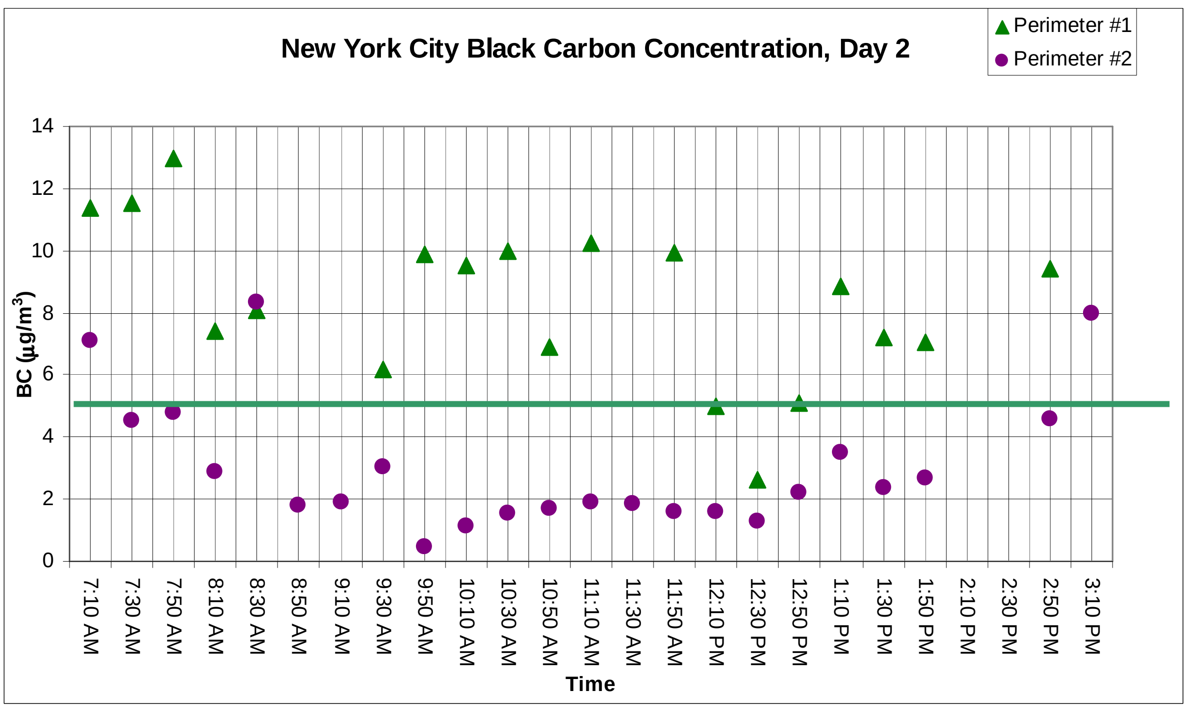


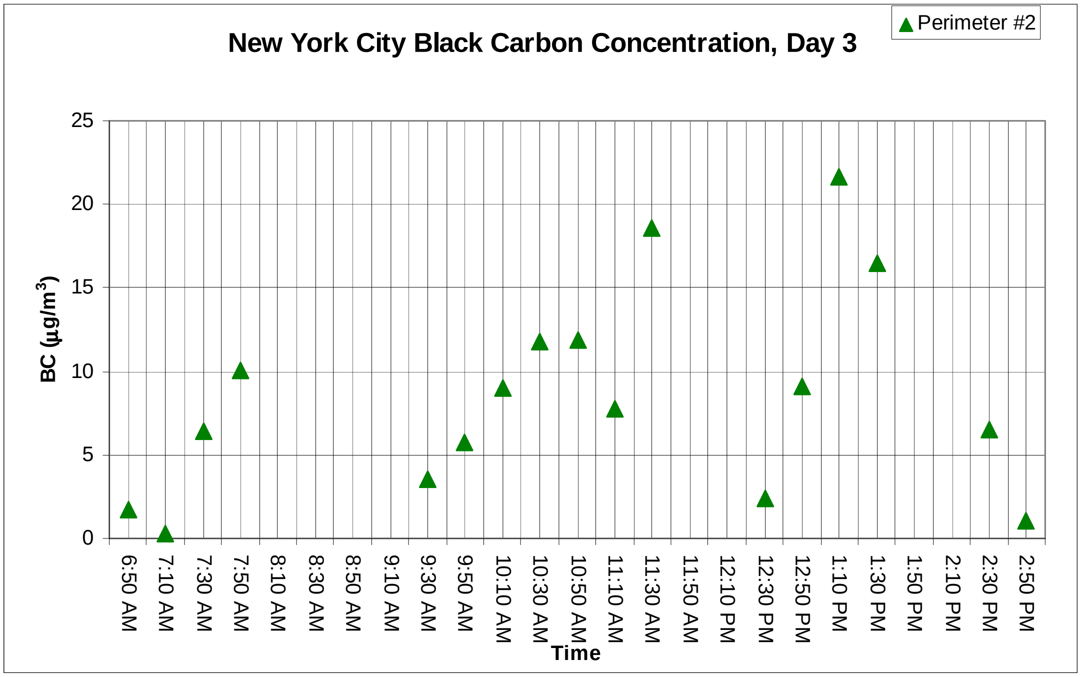
Manchester, NH Black Carbon Concentration, Day 2
Perimeter #1
BC (µg/m3)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
7:00 AM
7:20 AM
7:40 AM
8:00 AM
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
Time

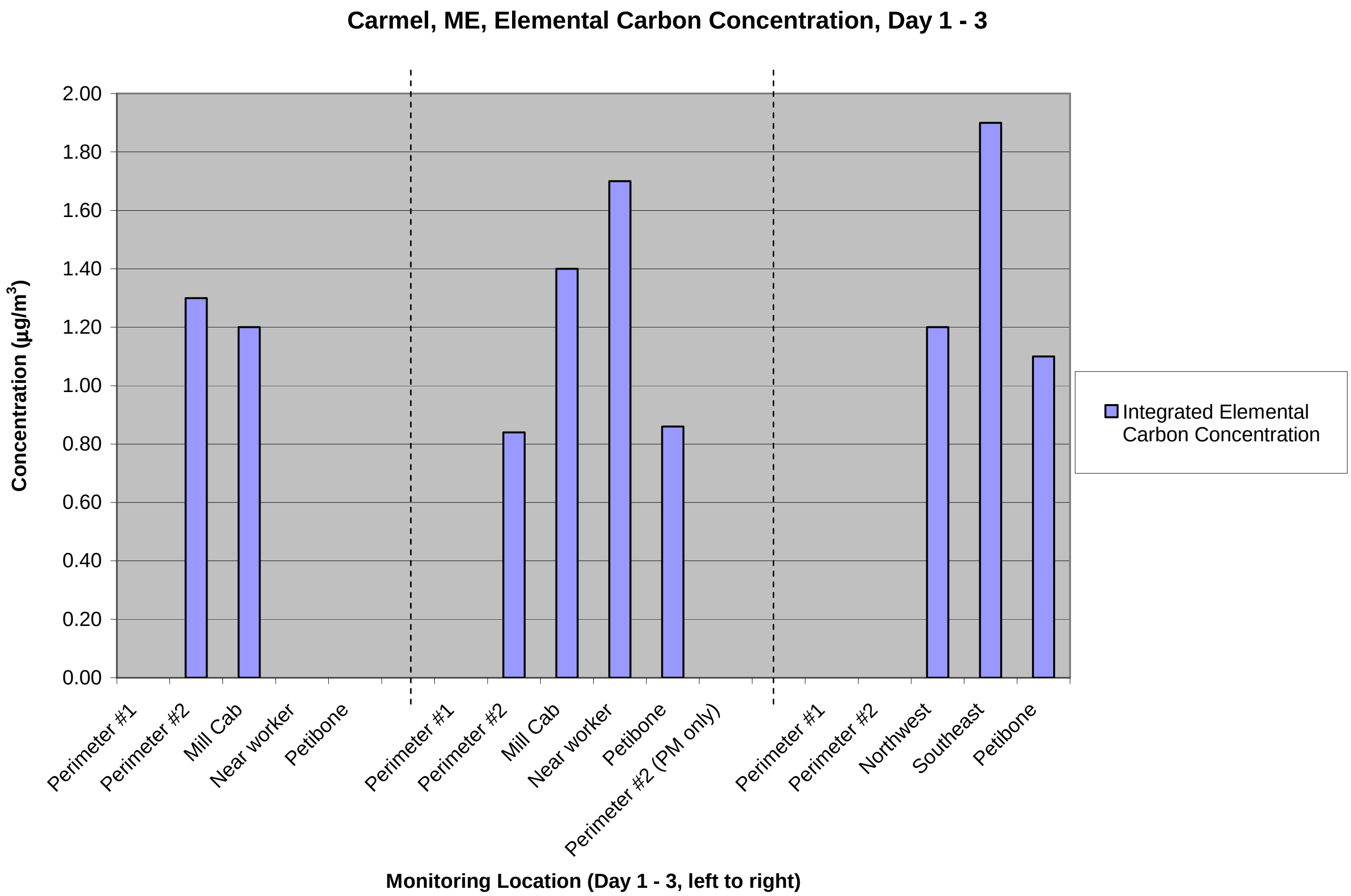


Manchester, NH Black Carbon Concentration, Day 3
Perimeter #1
BC (µg/m3)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
7:00 AM
7:20 AM
7:40 AM
8:00 AM
8:20 AM
8:40 AM
9:00 AM
9:20 AM
9:40 AM
10:00 AM
10:20 AM
10:40 AM
11:00 AM
11:20 AM
11:40 AM
12:00 PM
12:20 PM
12:40 PM
1:00 PM
1:20 PM
1:40 PM
Time


New York City Black Carbon Concentrations, Day 1
Perimeter #1
Perimeter #2
BC (µg/m3)
25
20
15
10
5
0
7:25 AM
7:45 AM
8:05 AM
8:25 AM
8:45 AM
9:05 AM
9:25 AM
9:45 AM
10:05 AM
10:25 AM
10:45 AM
11:05 AM
11:25 AM
11:45 AM
12:05 PM
12:25 PM
12:45 PM
1:05 PM
1:25 PM
1:45 PM
2:05 PM
2:25 PM
2:45 PM
3:05 PM
3:25 PM
Time

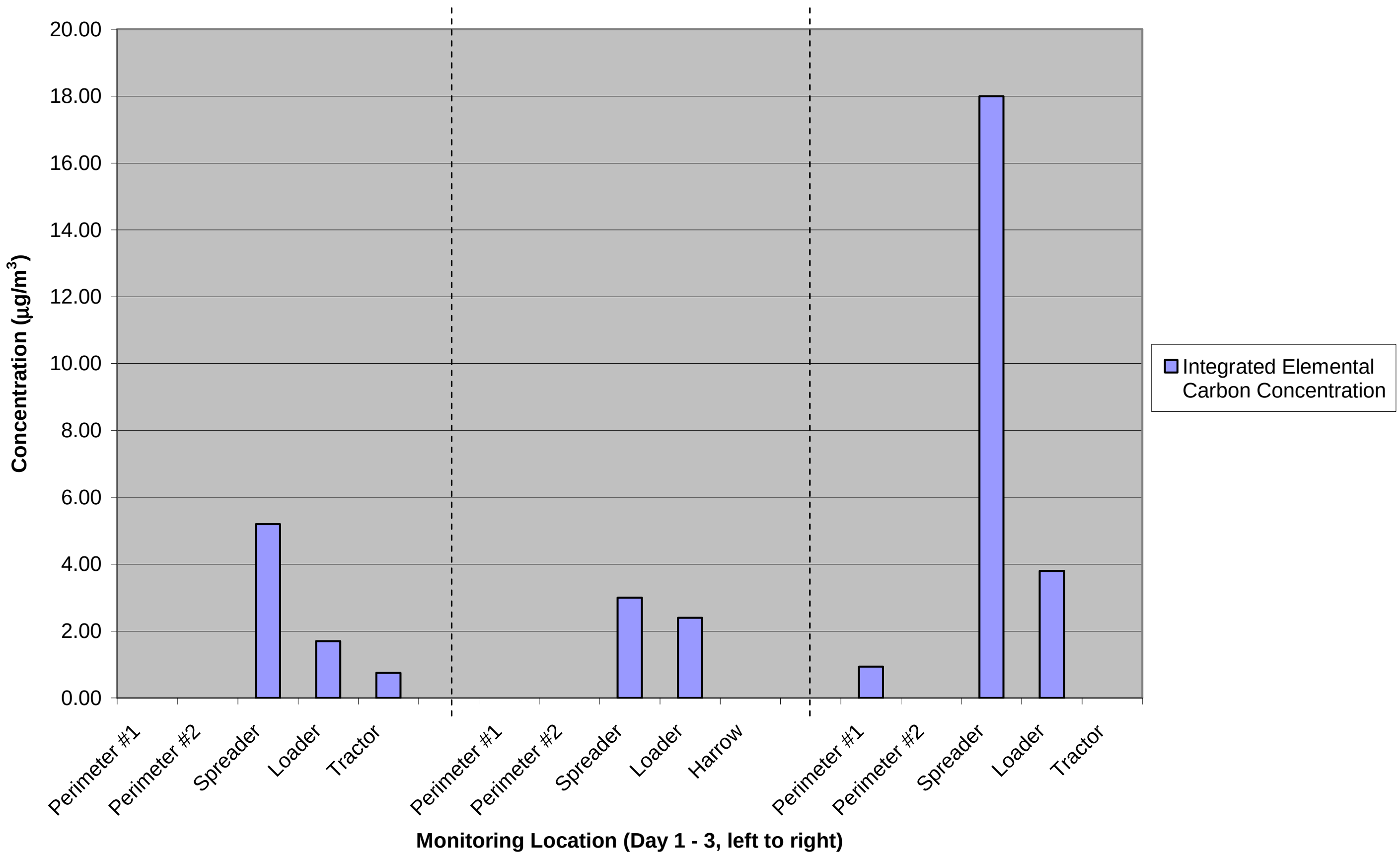

New York City Black Carbon Concentration, Day 2
Perimeter #1
Perimeter #2
BC (µg/m3)
14
12
10
8
6
4
2
0
7:10 AM
7:30 AM
7:50 AM
8:10 AM
8:30 AM
8:50 AM
9:10 AM
9:30 AM
9:50 AM
10:10 AM
10:30 AM
10:50 AM
11:10 AM
11:30 AM
11:50 AM
12:10 PM
12:30 PM
12:50 PM
1:10 PM
1:30 PM
1:50 PM
2:10 PM
2:30 PM
2:50 PM
3:10 PM
Time

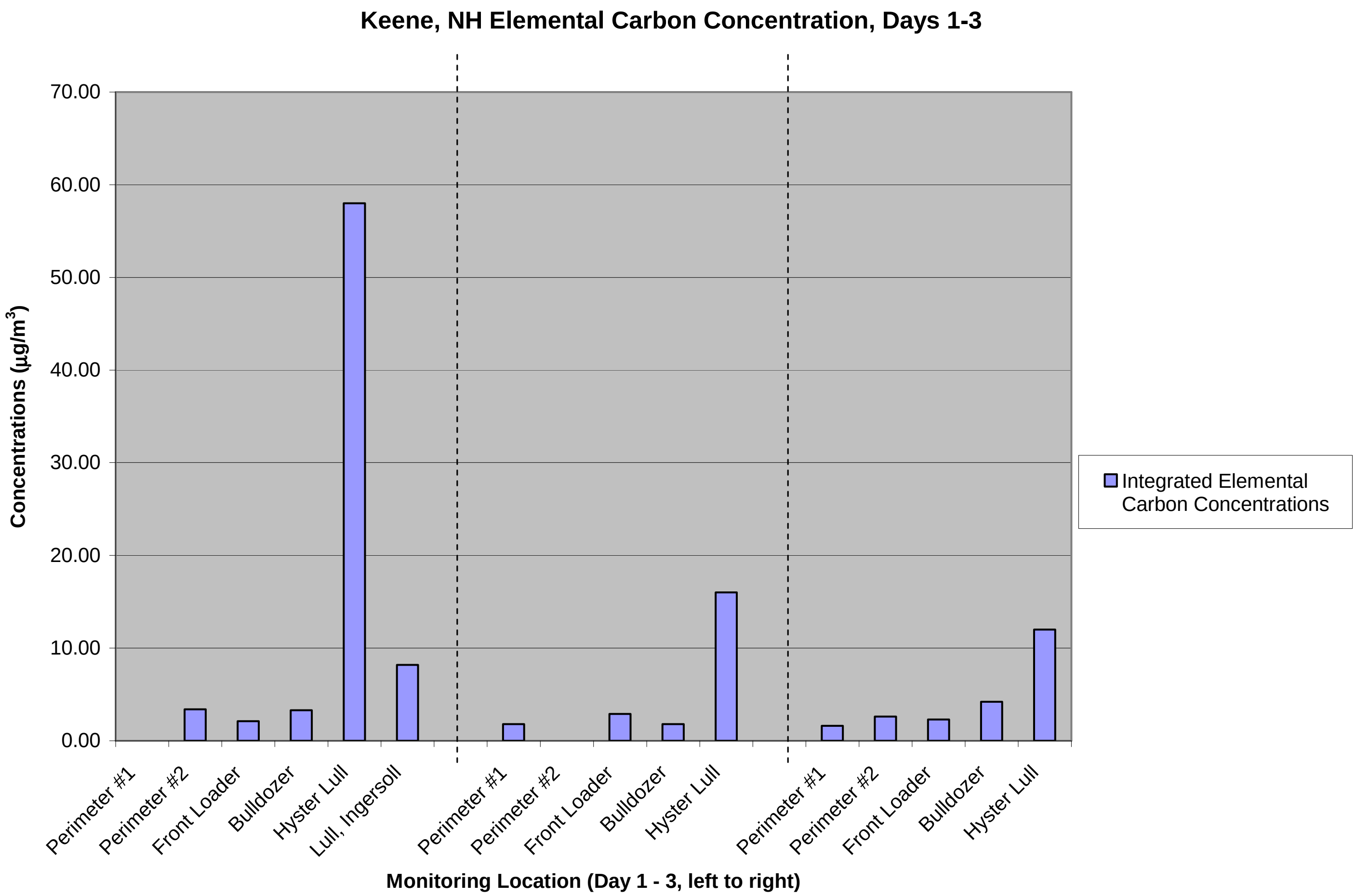

New York City Black Carbon Concentration, Day 3
Perimeter #2
BC (µg/m3)
25
20
15
10
5
0
6:50 AM
7:10 AM
7:30 AM
7:50 AM
8:10 AM
8:30 AM
8:50 AM
9:10 AM
9:30 AM
9:50 AM
10:10 AM
10:30 AM
10:50 AM
11:10 AM
11:30 AM
11:50 AM
12:10 PM
12:30 PM
12:50 PM
1:10 PM
1:30 PM
1:50 PM
2:10 PM
2:30 PM
2:50 PM
Time

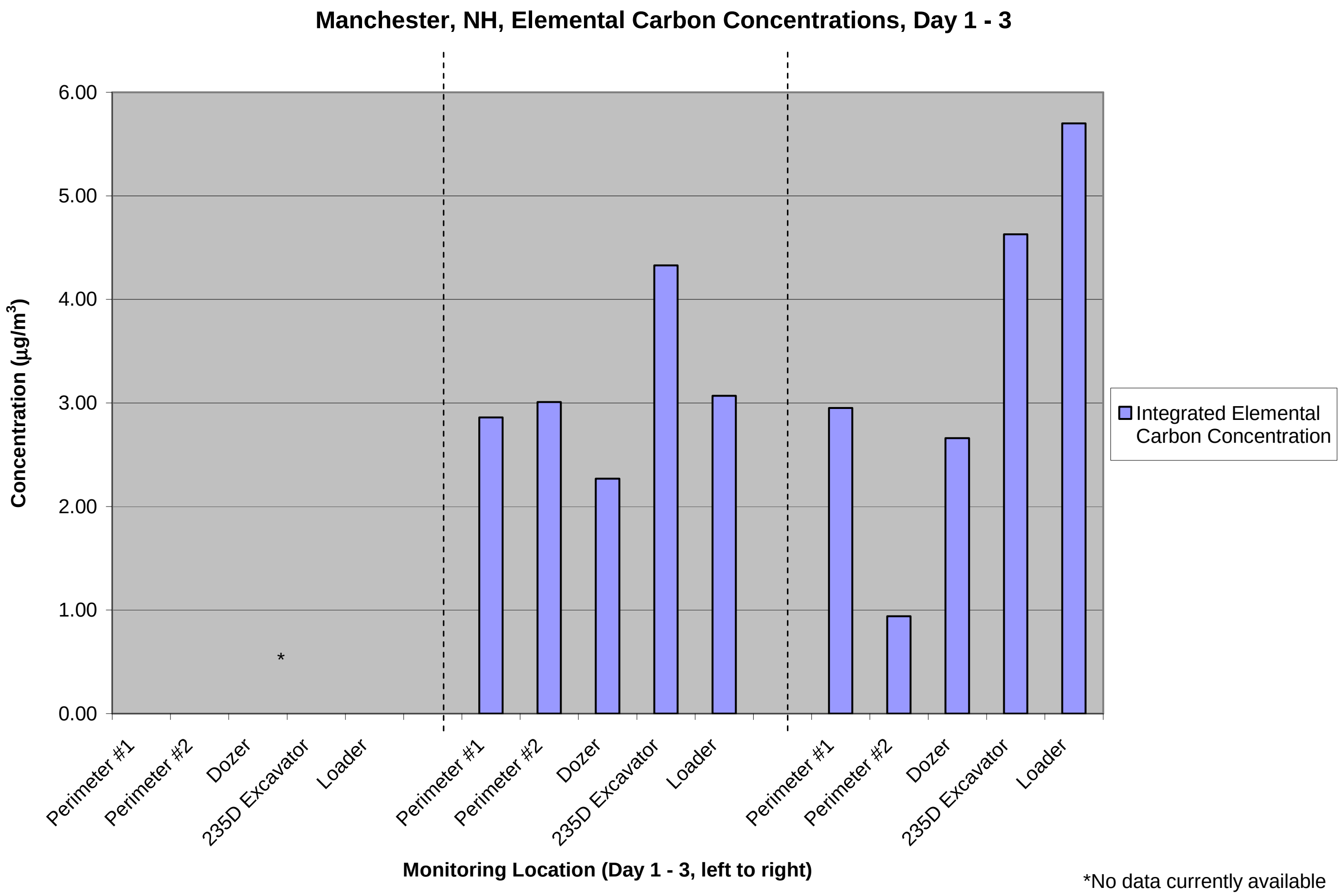


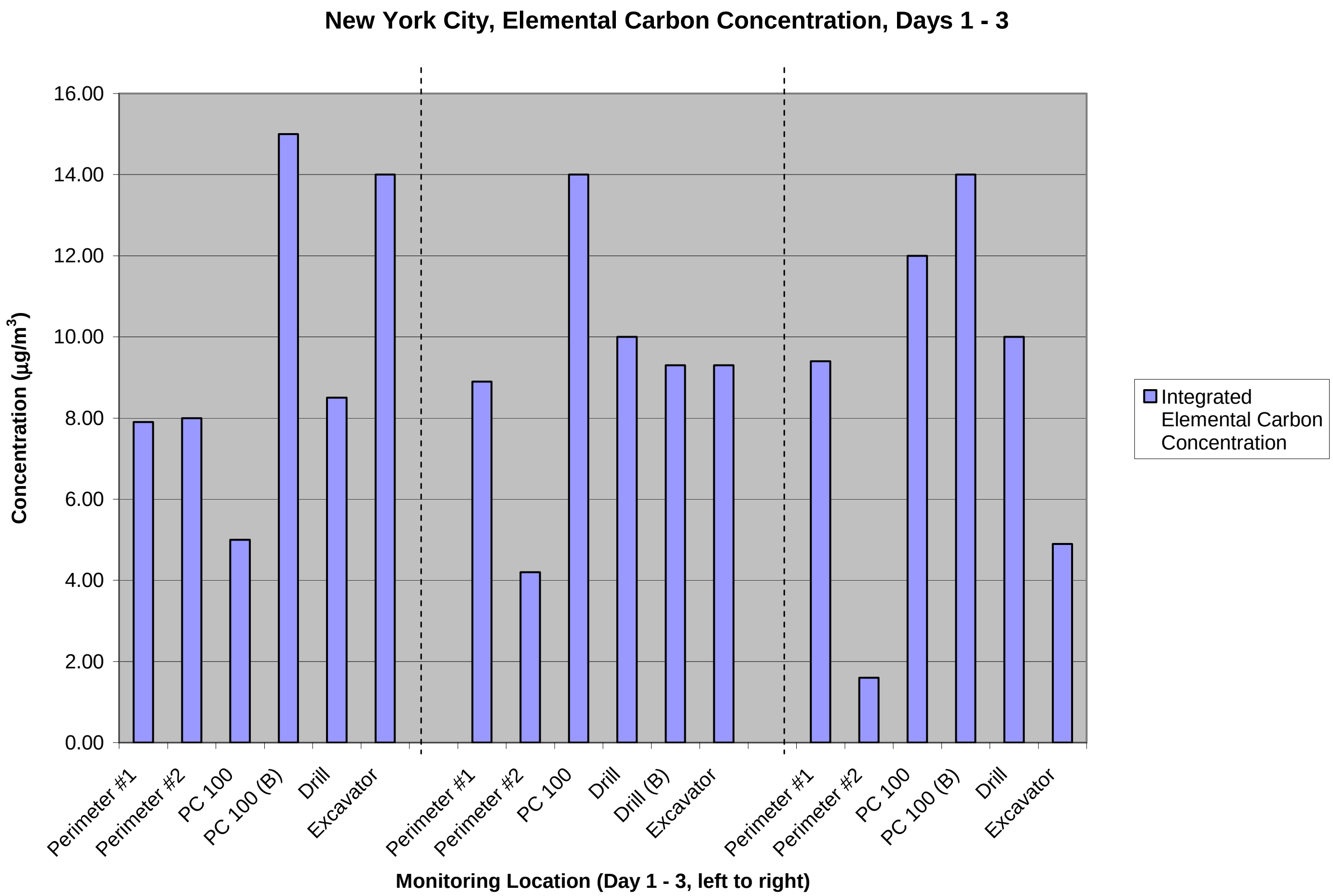
Carmel, ME, Elemental Carbon Concentration, Day 1 - 3
Concentration (µg/m3)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Perimeter #1
Perimeter #2
Mill Cab
Near worker
Petibone
Perimeter #1
Perimeter #2
Mill Cab
Near worker
Petibone
Perimeter #2 (PM only)
Perimeter #1
Perimeter #2
Northwest
Southeast
Petibone
Monitoring Location (Day 1 - 3, left to right)
Integrated Elemental Carbon Concentration

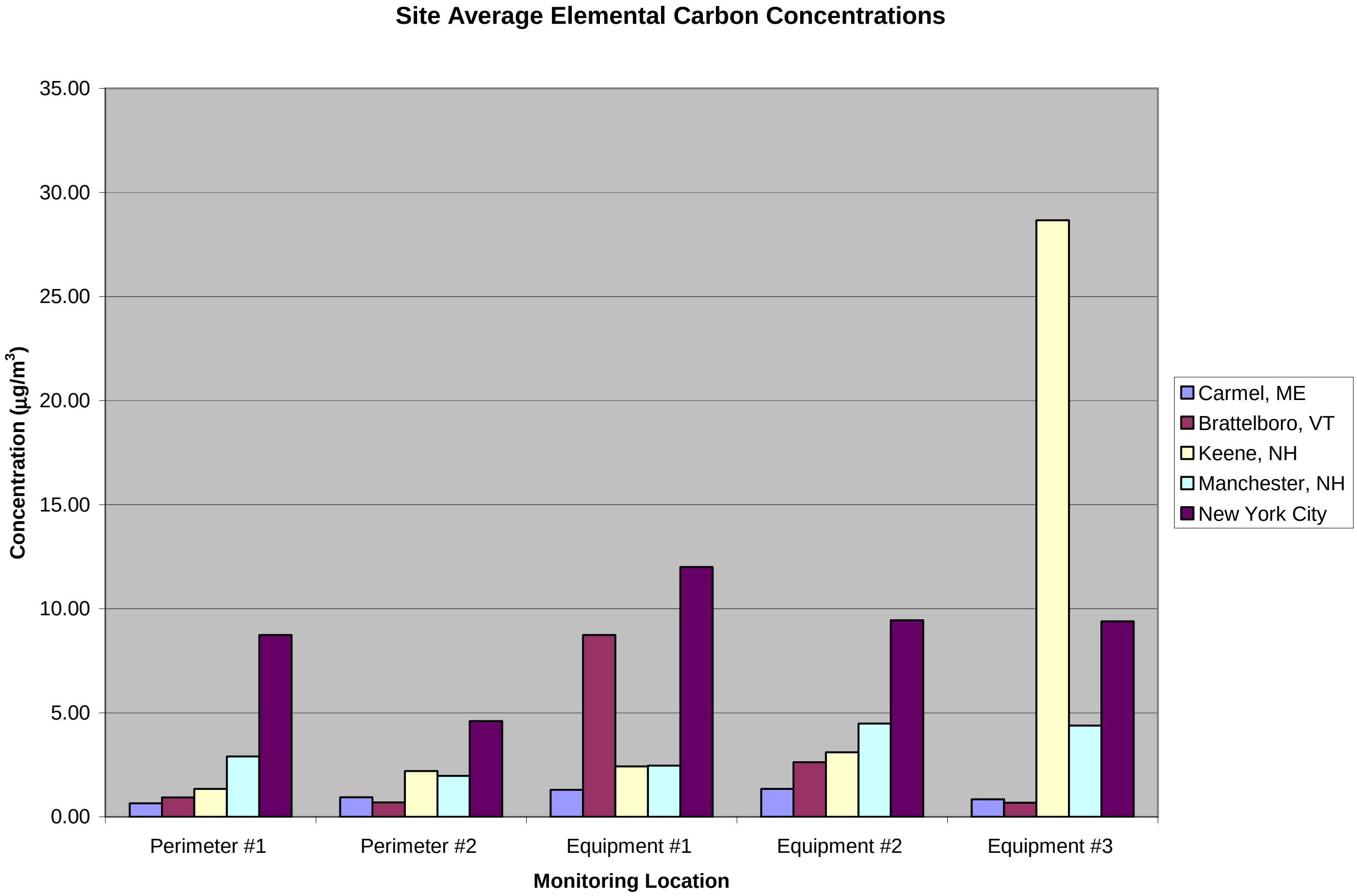
Brattelboro, VT, Elemental Carbon Concentration, Day 1 - 3




Keene, NH Elemental Carbon Concentration, Days 1-3
Concentrations (µg/m³)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull
Lull, Ingersoll
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull
Monitoring Location (Day 1 - 3, left to right)
Integrated Elemental Carbon Concentrations

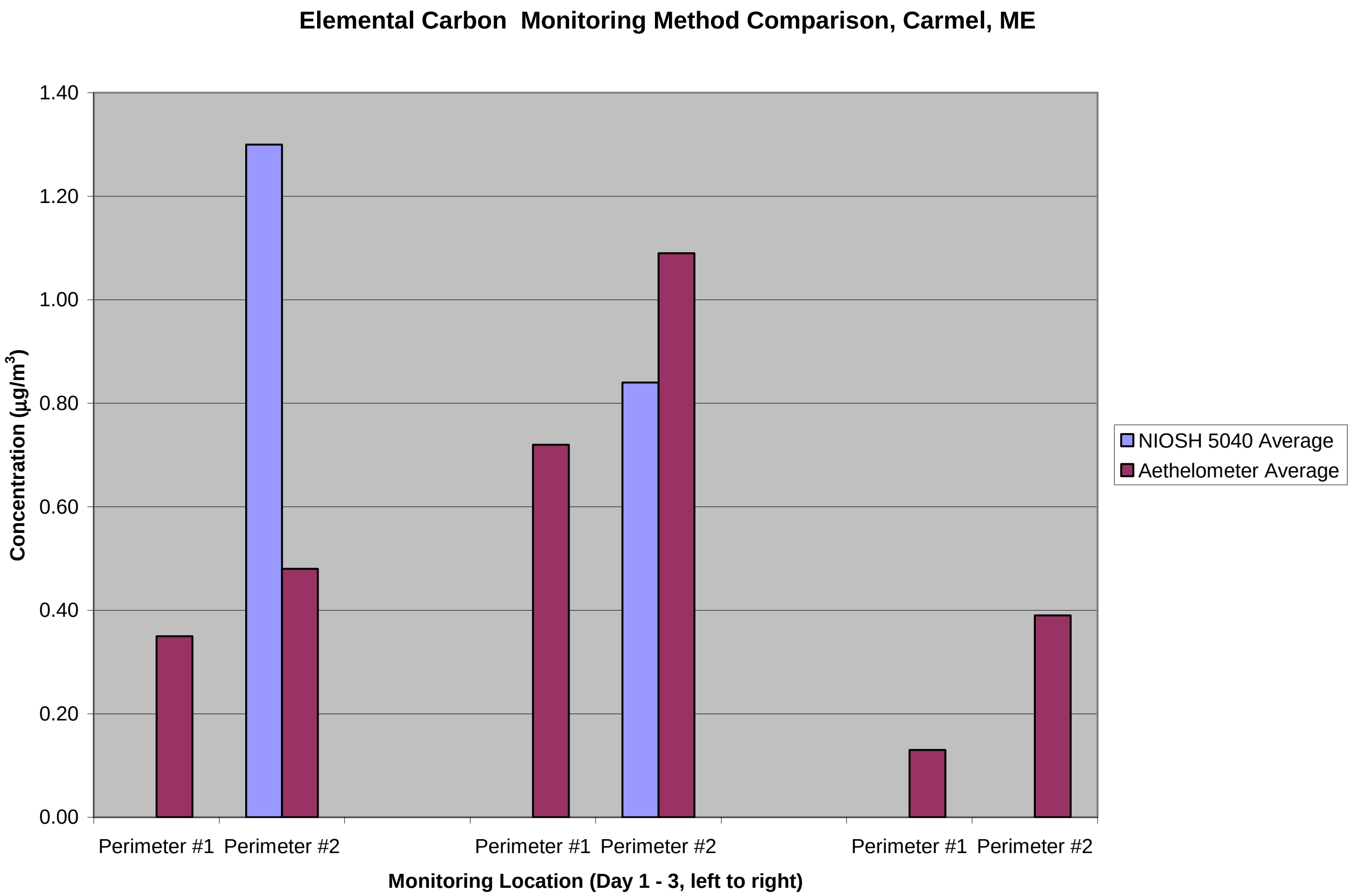

Manchester, NH, Elemental Carbon Concentrations, Day 1 - 3
Concentration (µg/m3)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
*
Integrated Elemental Carbon Concentration
Perimeter #1
Perimeter #2
Dozer
235D Excavator
Loader
Perimeter #1
Perimeter #2
Dozer
235D Excavator
Loader
Perimeter #1
Perimeter #2
Dozer
235D Excavator
Loader
Monitoring Location (Day 1 - 3, left to right)
*No data currently available


New York City, Elemental Carbon Concentration, Days 1 - 3
Concentration (µg/m3)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Integrated Elemental Carbon Concentration
Perimeter #1
Perimeter #2
PC 100
PC 100 (B)
Drill
Excavator
Perimeter #1
Perimeter #2
PC 100
Drill
Drill (B)
Excavator
Perimeter #1
Perimeter #2
PC 100
PC 100 (B)
Drill
Excavator
Monitoring Location (Day 1 - 3, left to right)

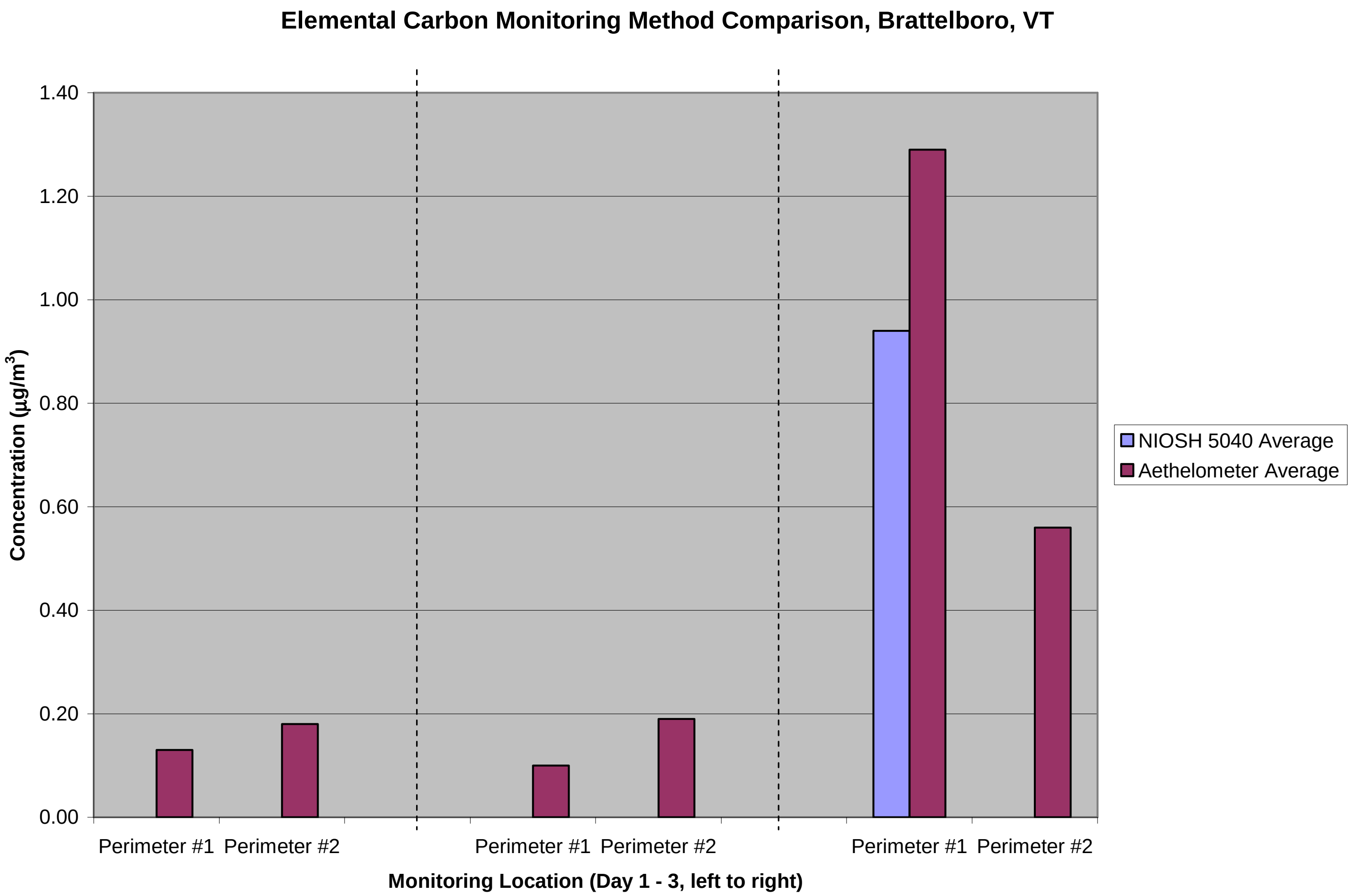


BC (aethelometer) and EC (NIOSH 5040) sampling methodology comparison.

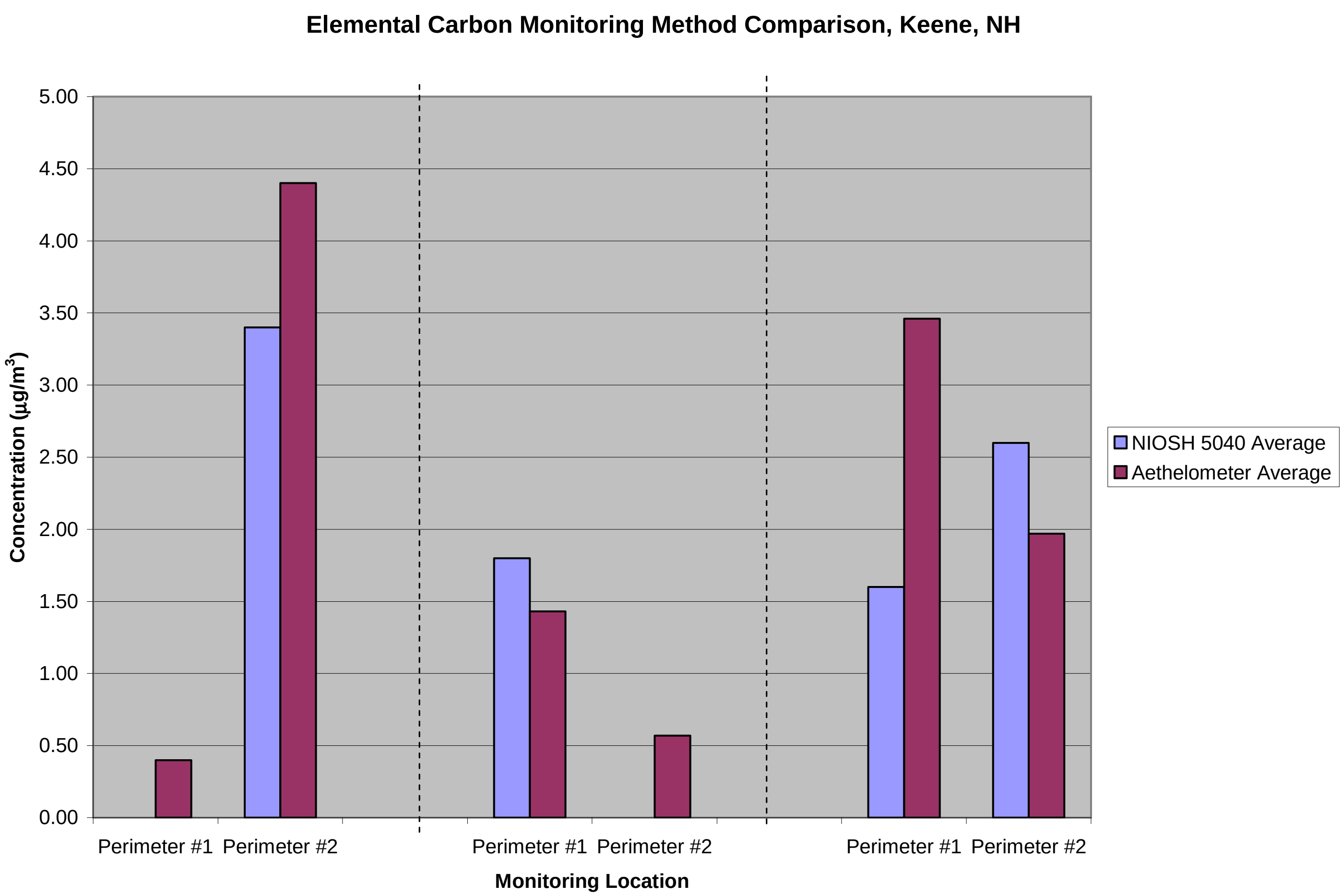
For each site, we compared the daily average, as calculated using 20-minute average concentrations measured by the aethelometer (black carbon), and the daily integrated sample analyzed using established elemental carbon and organic carbon quantification. The results of the comparison are presented below. These data suggest close agreement between these methods in more urban environments and a potential greater sensitivity in detecting black carbon concentrations using a calculated average from the real-time aethelometers than with the filter sampling analysis required in the NIOSH 5040 method.

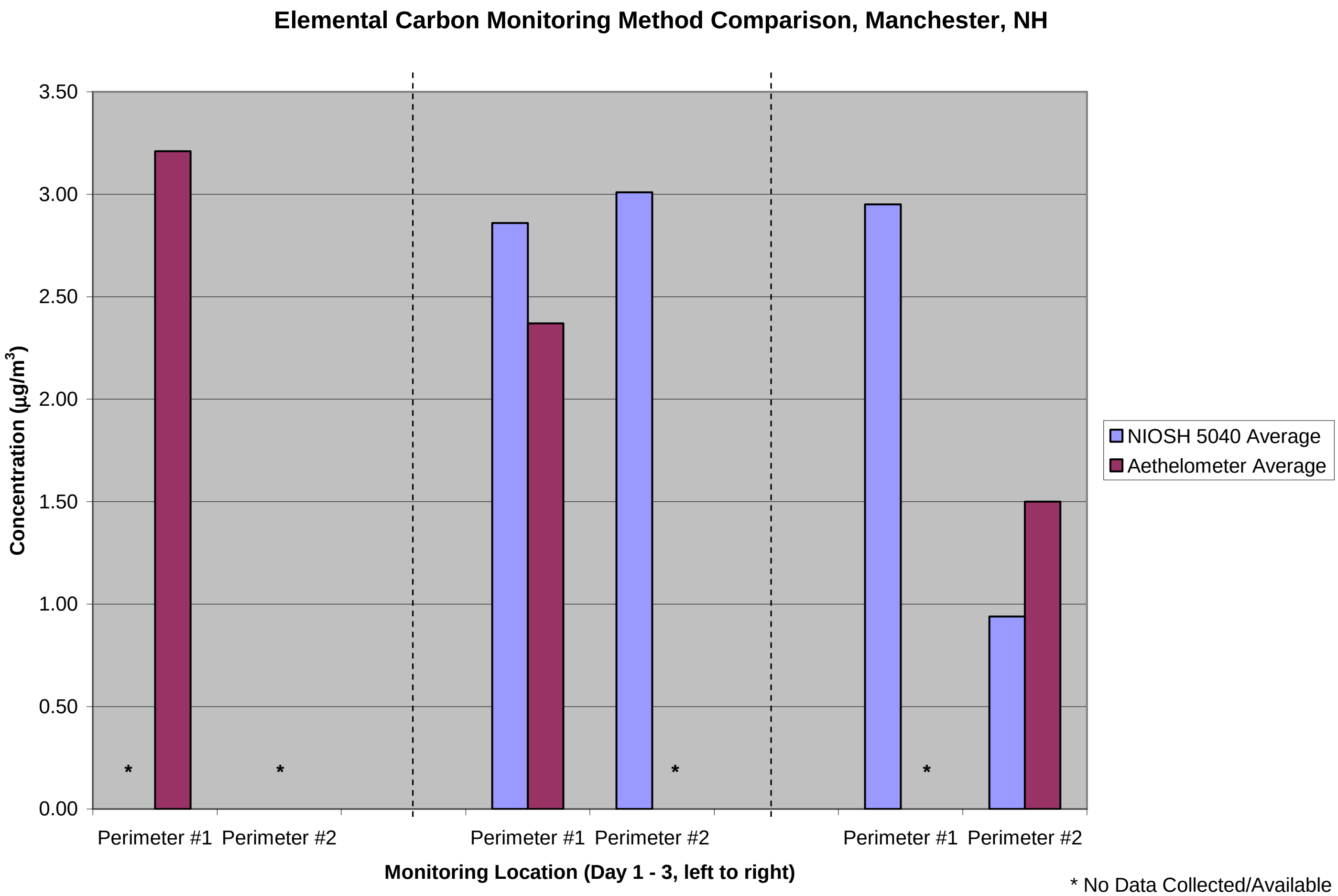


Elemental Carbon Monitoring Method Comparison, Carmel, ME
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Concentration (µg/m³)
NIOSH 5040 Average
Aethelometer Average
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Monitoring Location (Day 1 - 3, left to right)

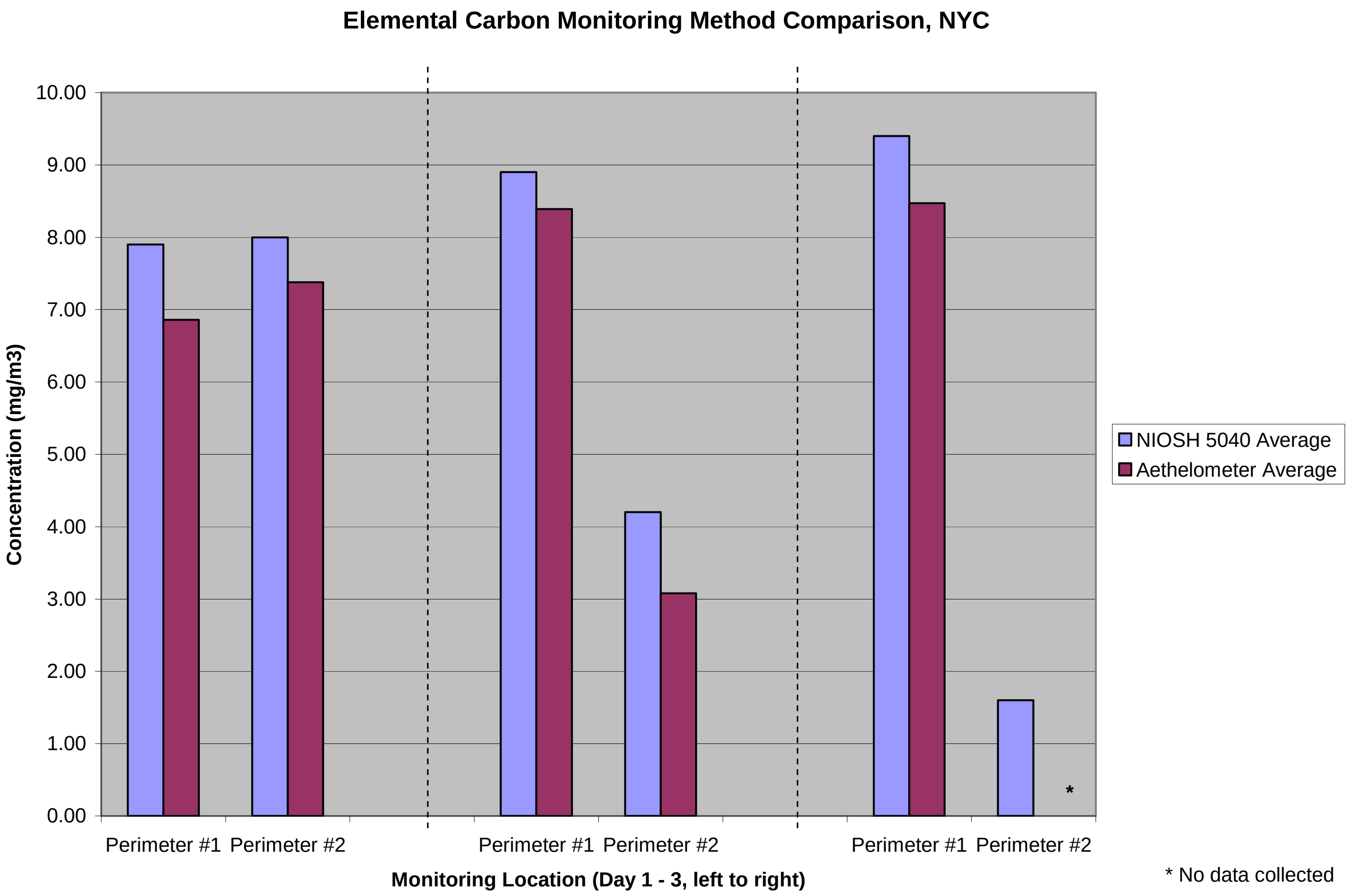


Elemental Carbon Monitoring Method Comparison, Brattelboro, VT
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Concentration (µg/m³)
NIOSH 5040 Average
Aethelometer Average
Perimeter #1 Perimeter #2
Perimeter #1 Perimeter #2
Perimeter #1 Perimeter #2
Monitoring Location (Day 1 - 3, left to right)


Elemental Carbon Monitoring Method Comparison, Keene, NH
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Concentration (µg/m3)
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Monitoring Location
NIOSH 5040 Average
Aethelometer Average

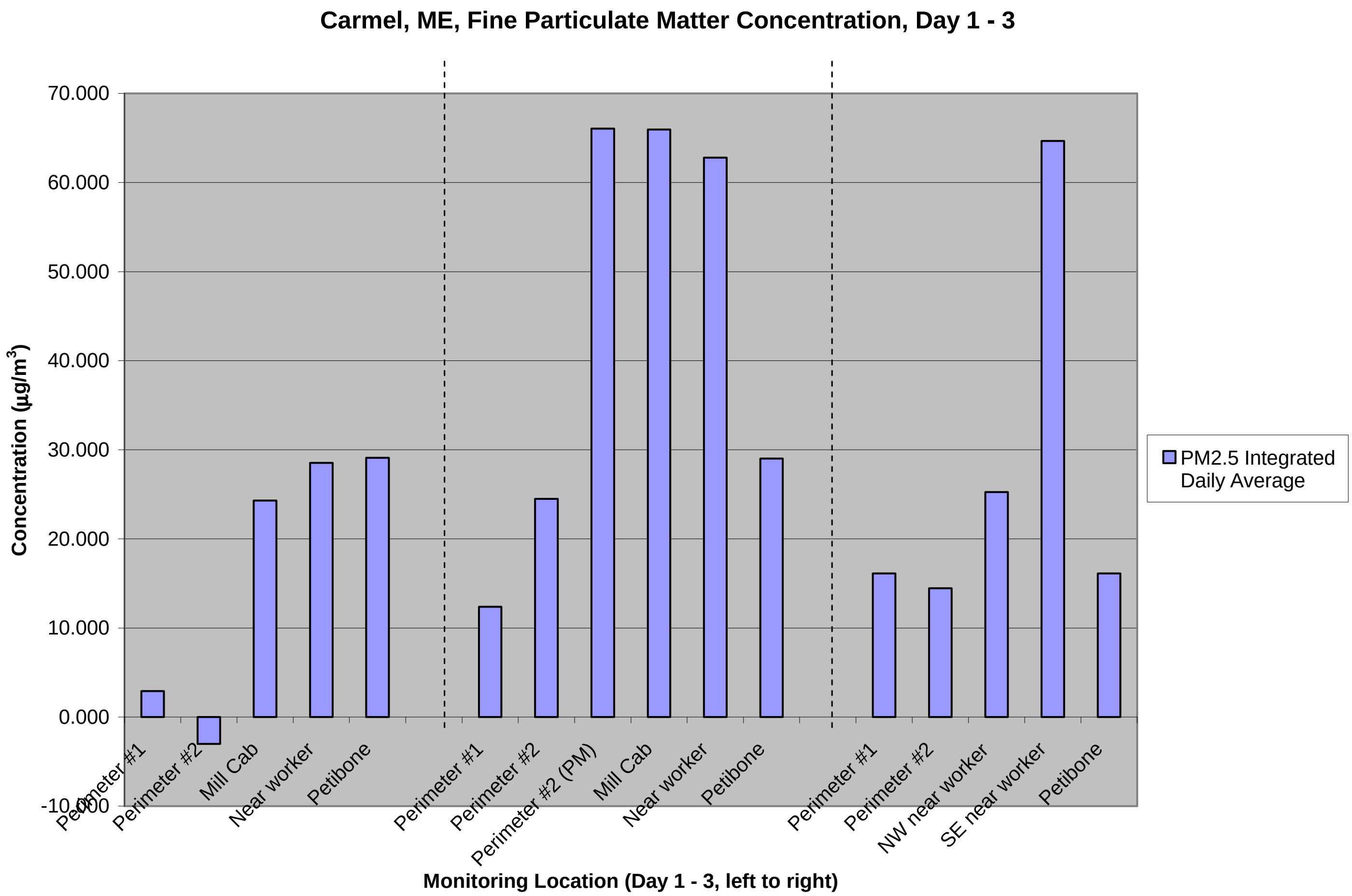


Elemental Carbon Monitoring Method Comparison, Manchester, NH
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Concentration (µg/m3)
*
*
*
*
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Monitoring Location (Day 1 - 3, left to right)
NIOSH 5040 Average
Aethelometer Average
* No Data Collected/Available

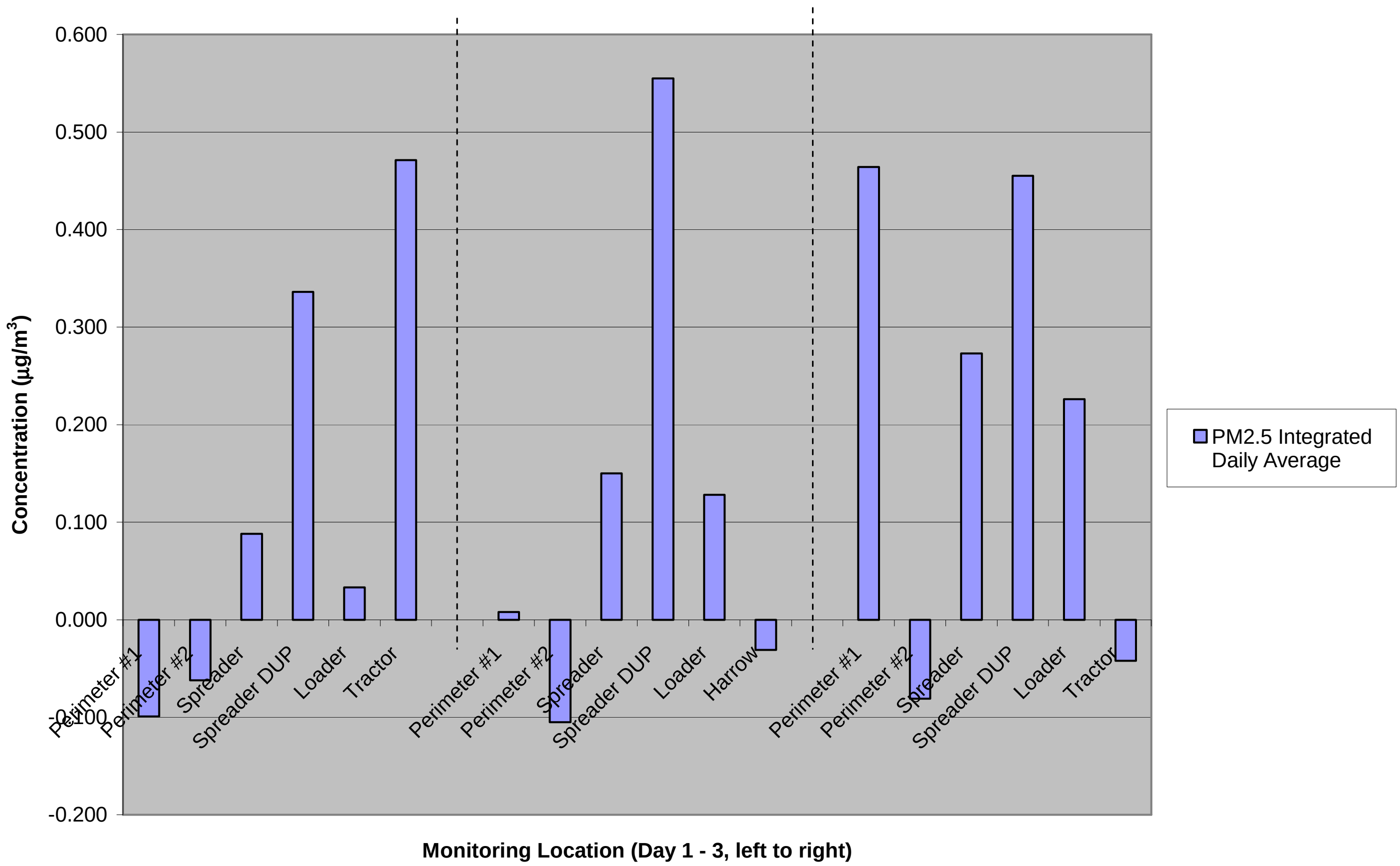

Elemental Carbon Monitoring Method Comparison, NYC
Concentration (mg/m3)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
*
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Perimeter #1
Perimeter #2
Monitoring Location (Day 1 - 3, left to right)
NIOSH 5040 Average
Aethelometer Average
* No data collected

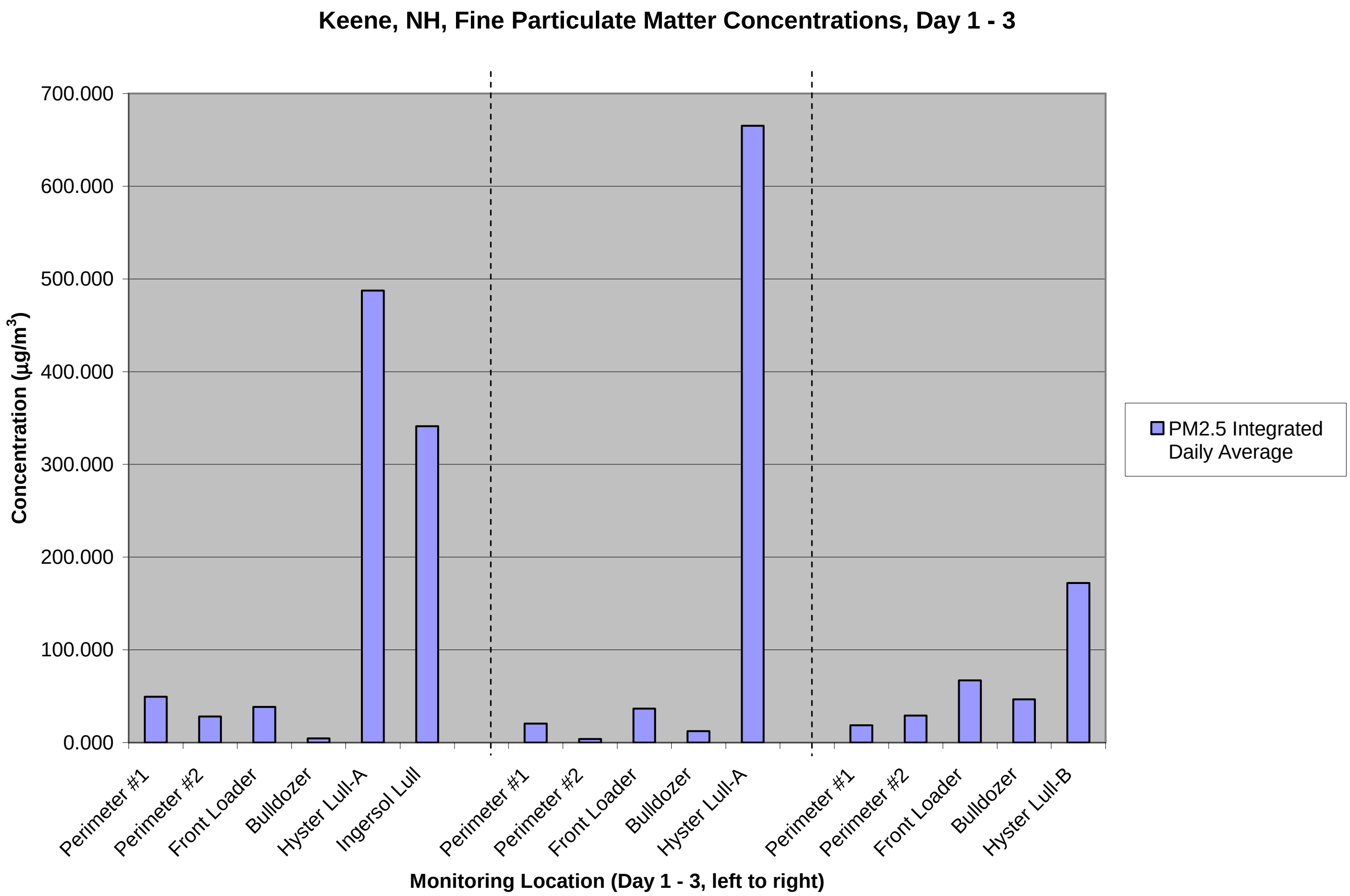
Daily Average Exposures to $PM_{2.5}$ and Comparison of Variability of All Sites Assessed

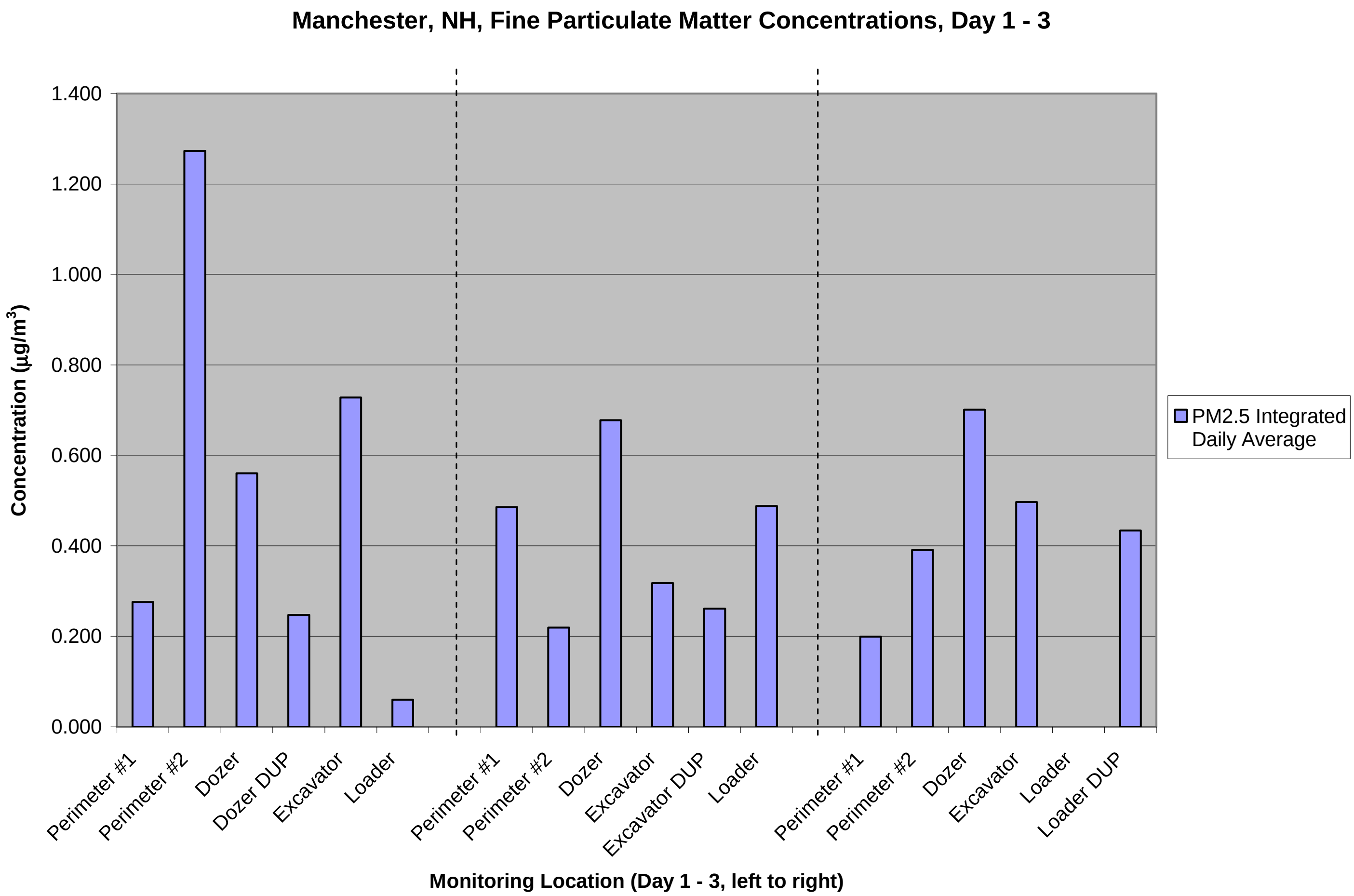
Daily average exposure to $PM_{2.5}$ for all sites illustrate an increase in area ambient exposures above that normally expected. At all sites, nonroad equipment activity increases the concentration typically monitored in the area. Typical daily ambient fine particulate matter concentrations for monitoring sites are: Carmel, ME 4-5 $\mu g/m^3$; Brattleboro, VT 4-5 $\mu g/m^3$; Keene, NH 14 $\mu g/m^3$; Manchester, NH 13-15 $\mu g/m^3$; and New York City 22 $\mu g/m^3$.

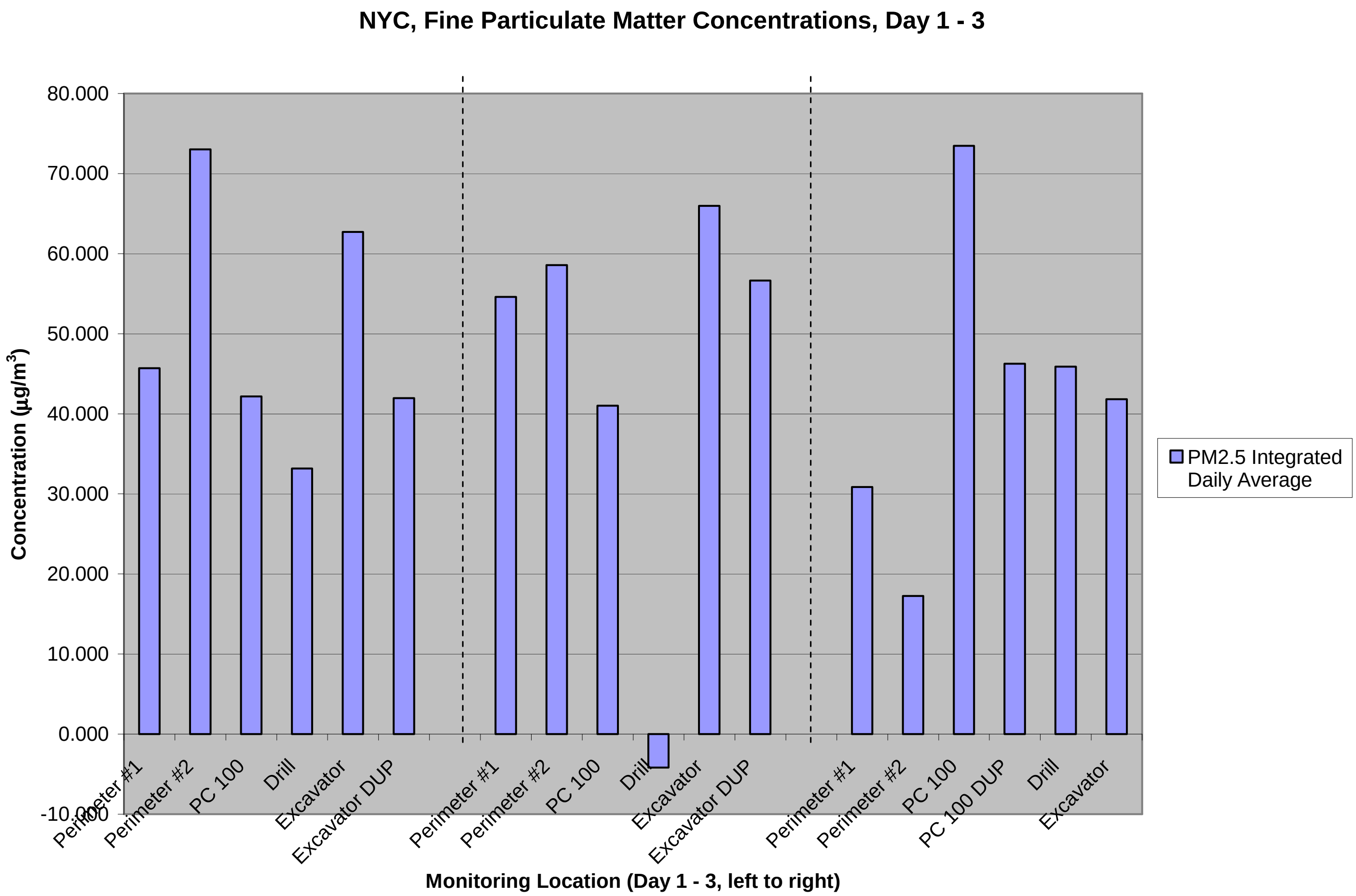


Brattelboro, VT, Fine Particulate Matter Concentration, Day 1 - 3

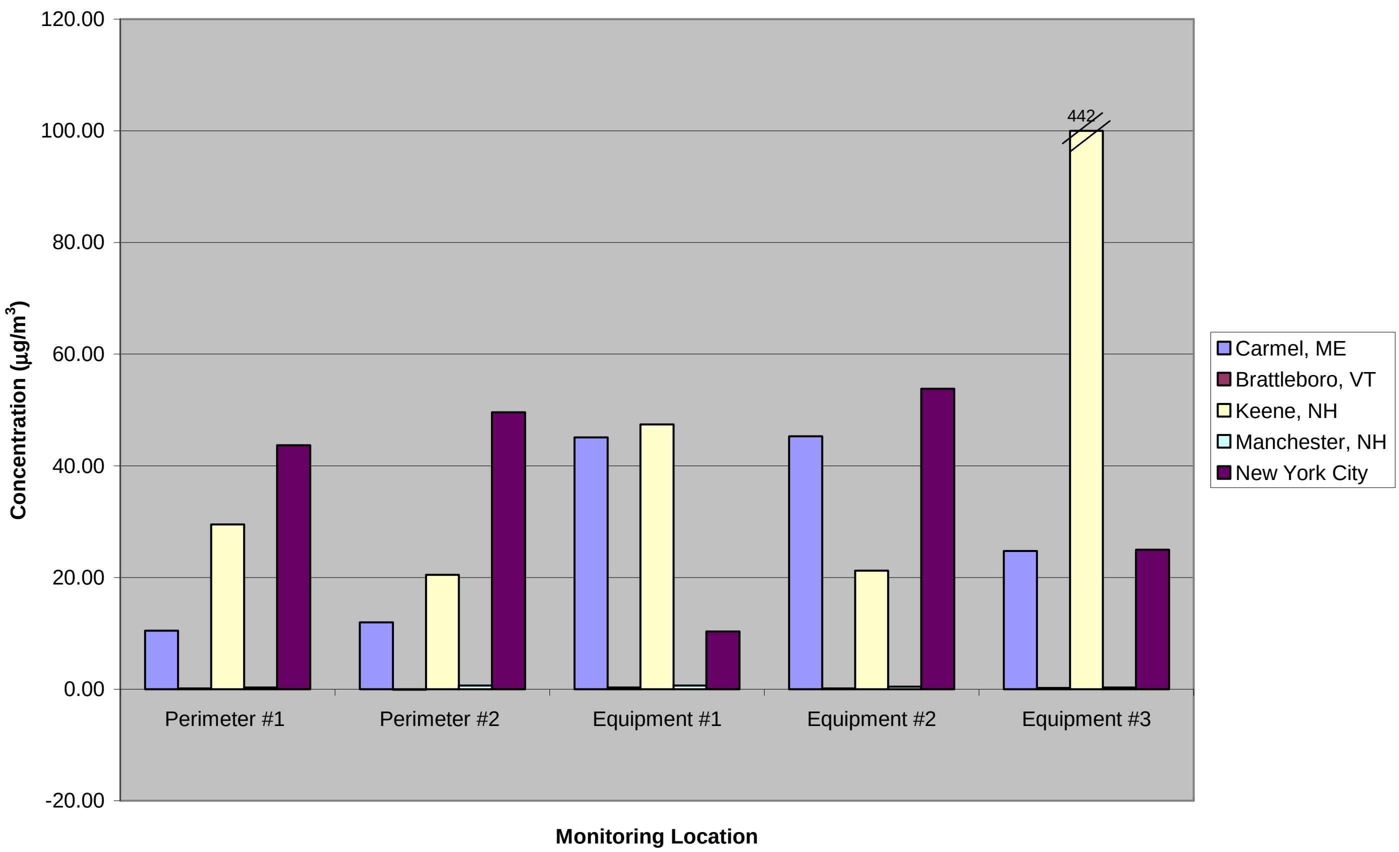



Keene, NH, Fine Particulate Matter Concentrations, Day 1 - 3
700.000
600.000
500.000
400.000
300.000
200.000
100.000
0.000
Concentration (µg/m3)
PM2.5 Integrated Daily Average
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull-A
Ingersol Lull
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull-A
Perimeter #1
Perimeter #2
Front Loader
Bulldozer
Hyster Lull-B
Monitoring Location (Day 1 - 3, left to right)


Manchester, NH, Fine Particulate Matter Concentrations, Day 1 - 3
Concentration (µg/m3)
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
PM2.5 Integrated Daily Average
Perimeter #1
Perimeter #2
Dozer
Dozer DUP
Excavator
Loader
Perimeter #1
Perimeter #2
Dozer
Excavator
Excavator DUP
Loader
Perimeter #1
Perimeter #2
Dozer
Excavator
Loader
Loader DUP
Monitoring Location (Day 1 - 3, left to right)

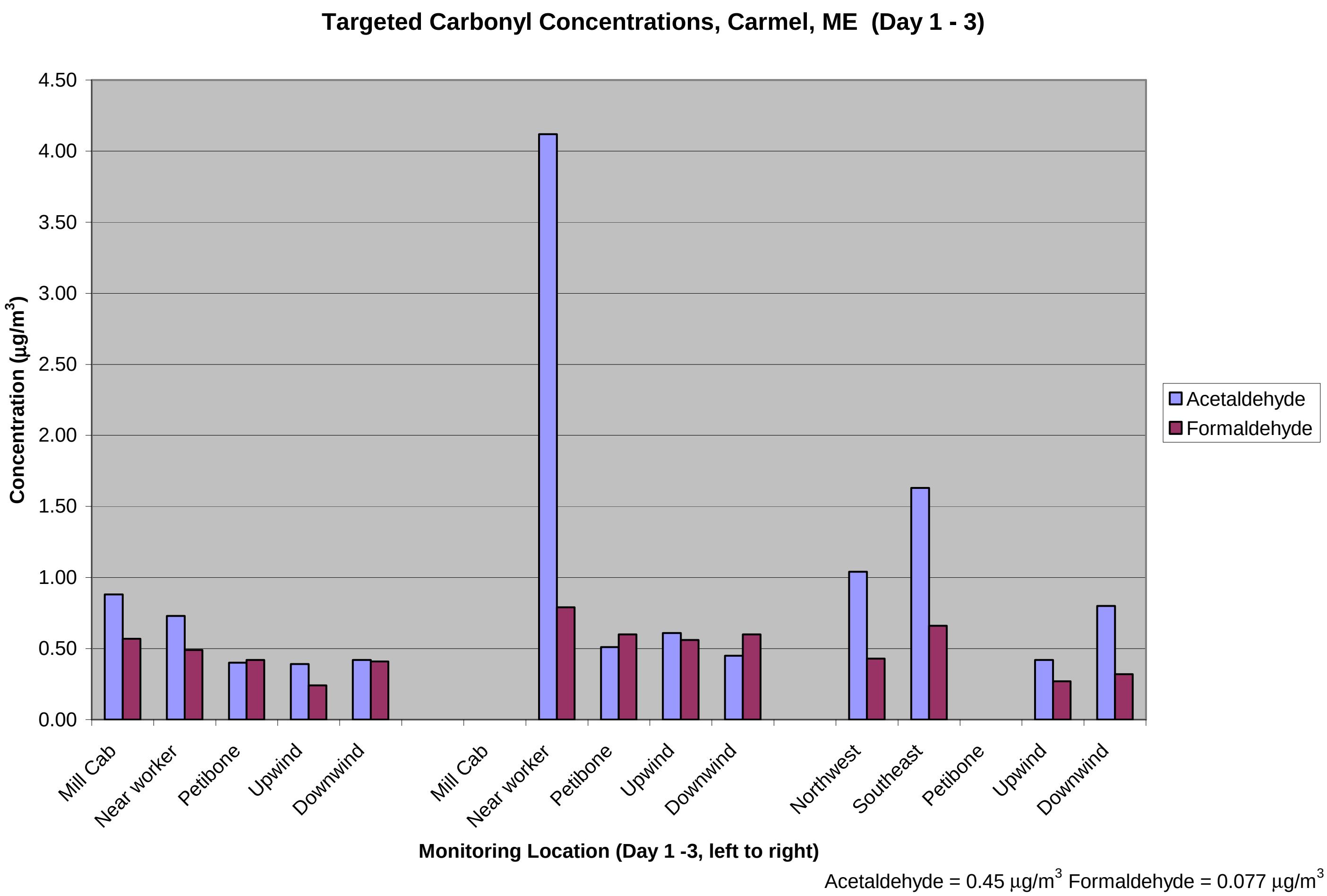

NYC, Fine Particulate Matter Concentrations, Day 1 - 3
Concentration (µg/m3)
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
-10.000
Perimeter #1
Perimeter #2
PC 100
Drill
Excavator
Excavator DUP
Perimeter #1
Perimeter #2
PC 100
Drill
Excavator
Excavator DUP
Perimeter #1
Perimeter #2
PC 100
PC 100 DUP
Drill
Excavator
Monitoring Location (Day 1 - 3, left to right)
PM2.5 Integrated Daily Average

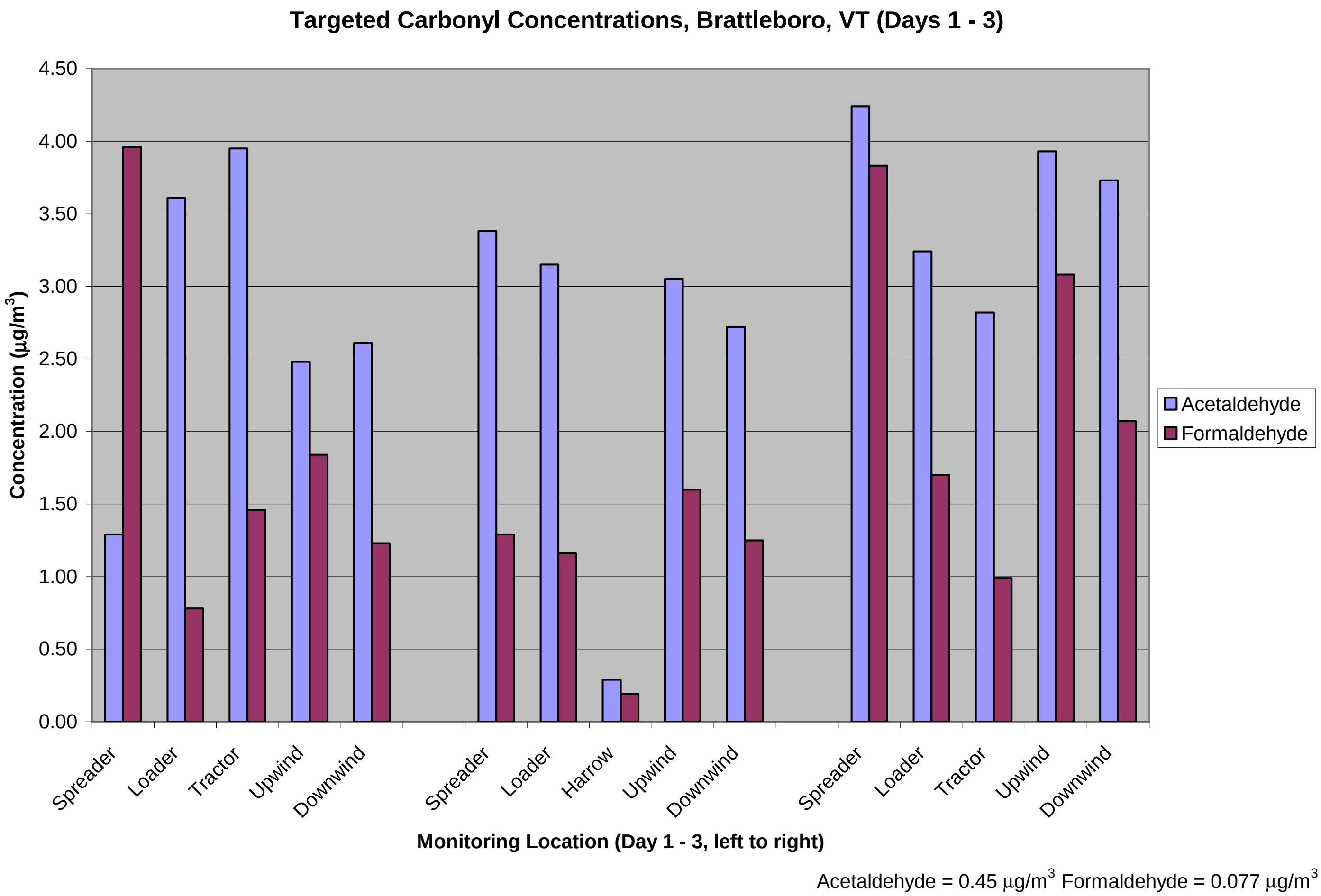
Site Average Fine Particulate Matter

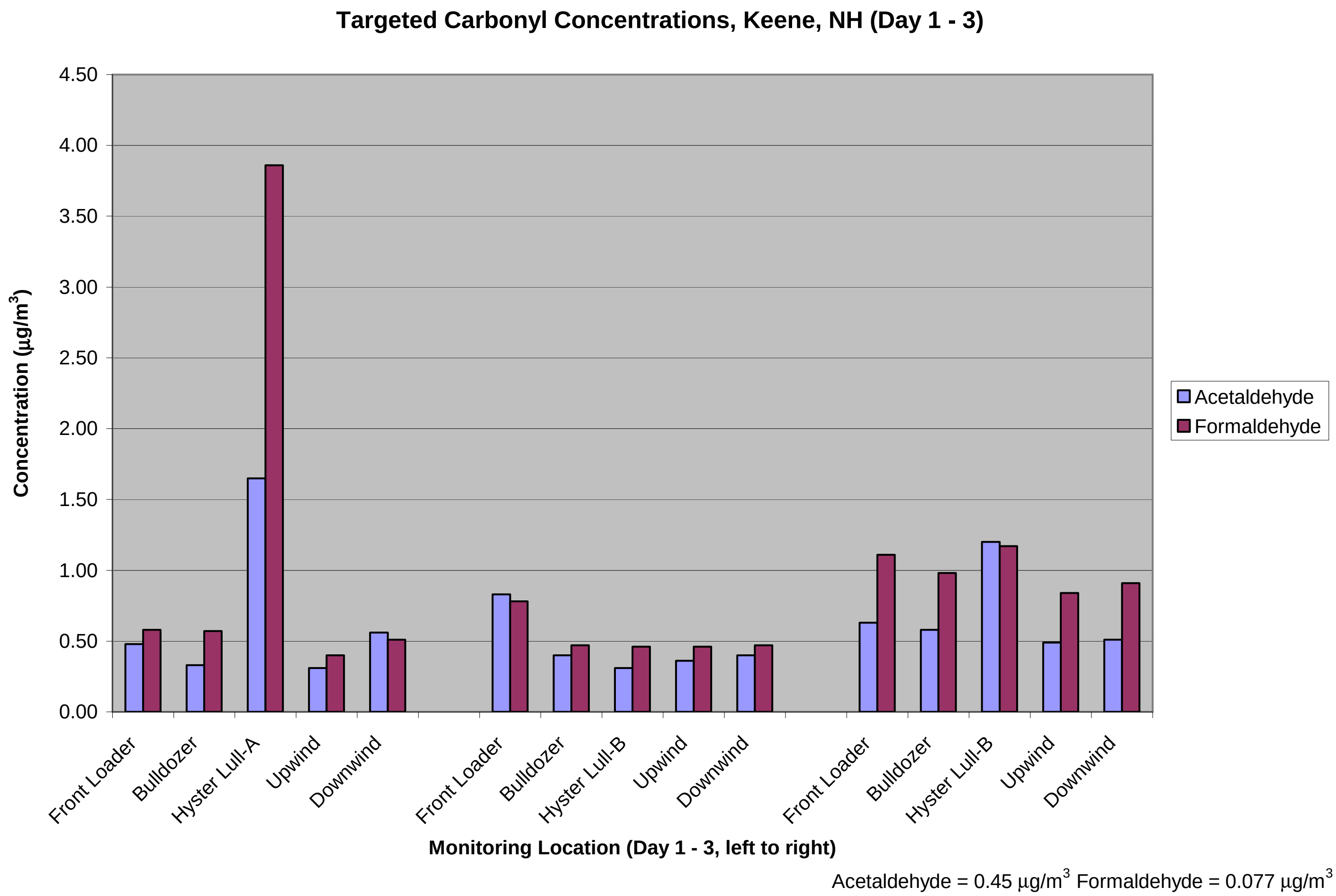


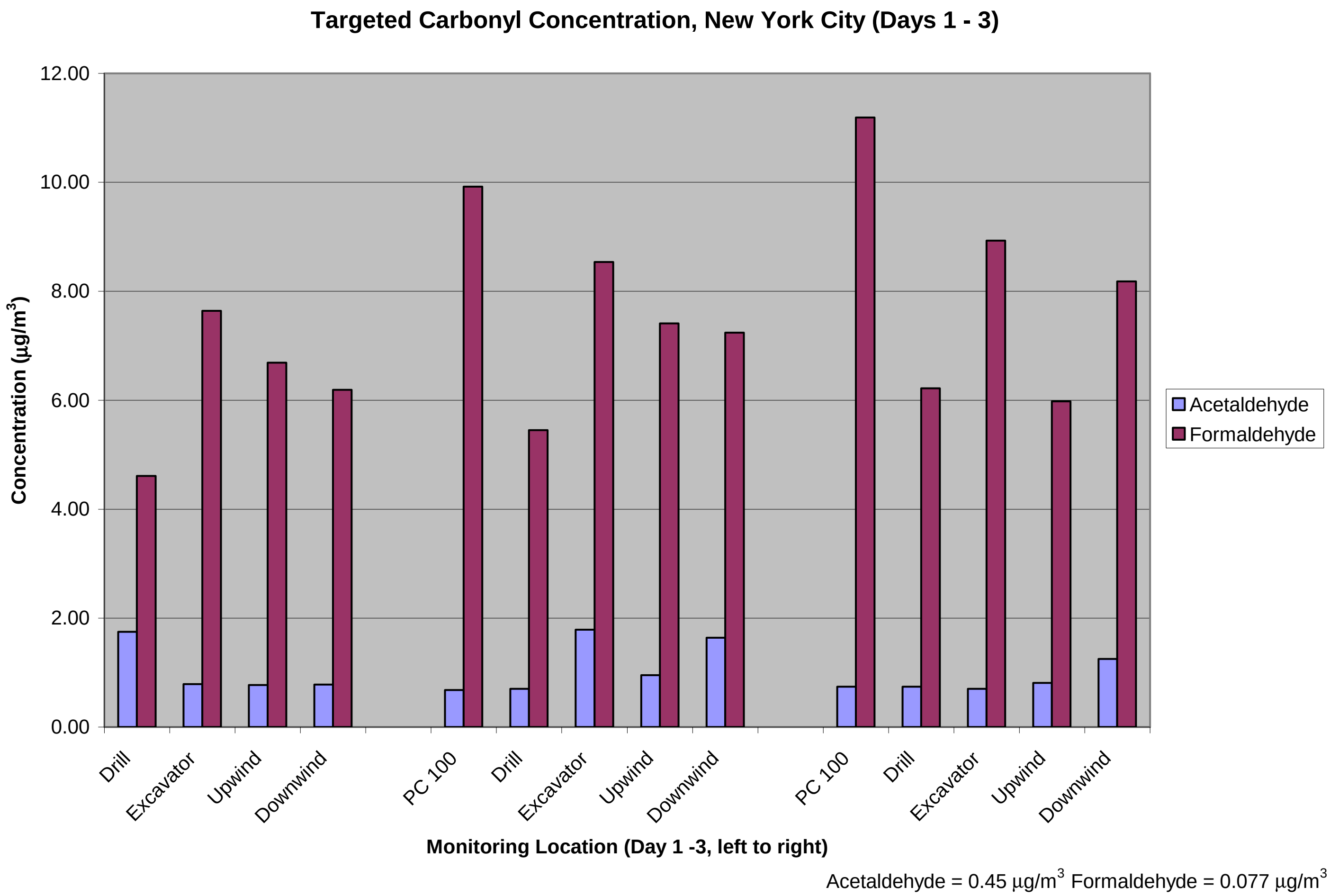
Daily Exposures to Gaseous Toxicants:

Monitored concentrations for acetaldehyde and formaldehyde exceed conservative risk screening thresholds for cancer as illustrated in the following figures. Note the one in one million risk screening threshold for acetaldehyde and formaldehyde are shown in the lower right corner of each figure. Data are not available for the Manchester, NH roadway construction site.



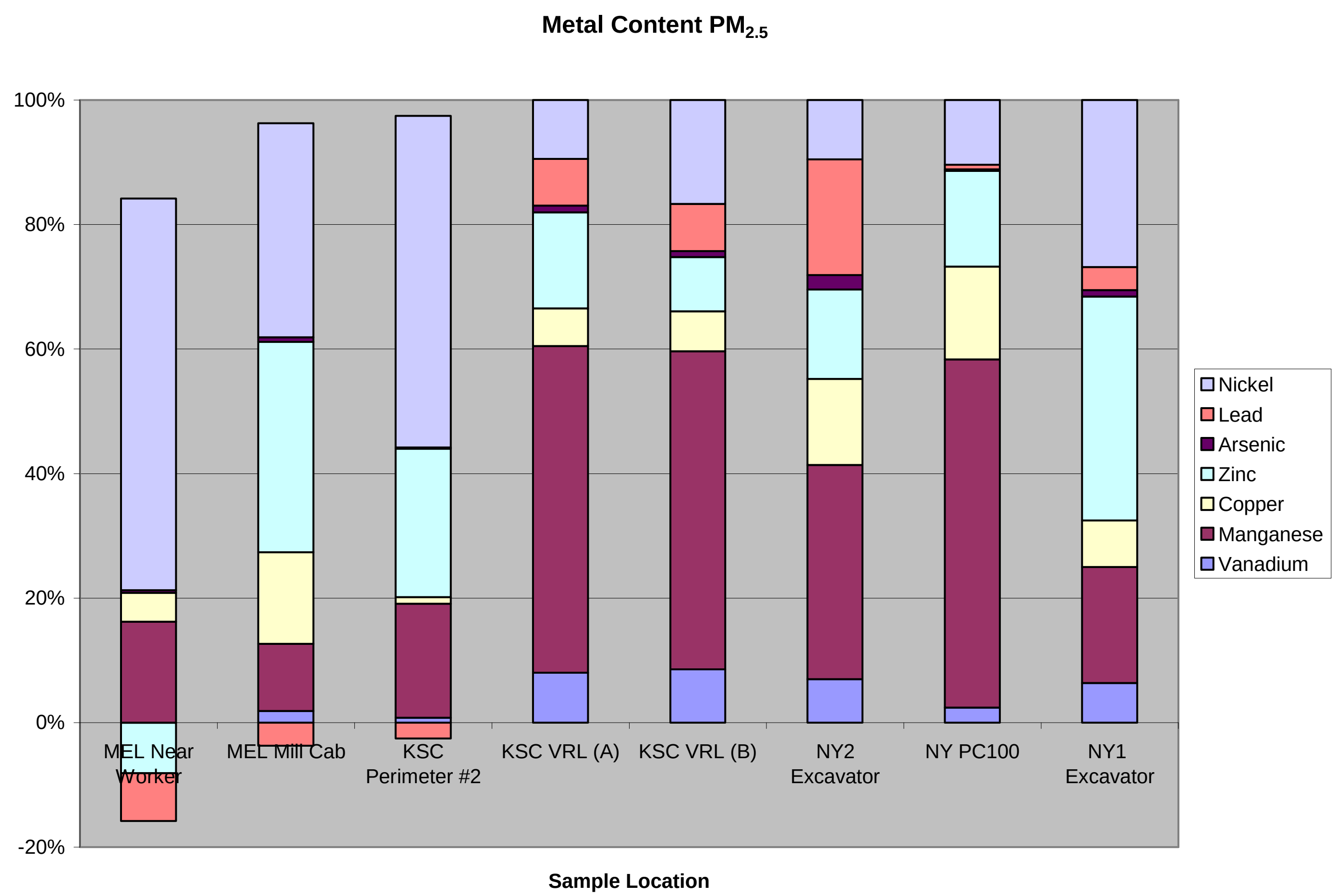

Targeted Carbonyl Concentrations, Brattleboro, VT (Days 1 - 3)
Concentration (µg/m³)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Spreader
Loader
Tractor
Upwind
Downwind
Spreader
Loader
Harrow
Upwind
Downwind
Spreader
Loader
Tractor
Upwind
Downwind
Monitoring Location (Day 1 - 3, left to right)
Acetaldehyde
Formaldehyde
Acetaldehyde = 0.45 µg/m³ Formaldehyde = 0.077 µg/m³


Targeted Carbonyl Concentrations, Keene, NH (Day 1 - 3)
Concentration (µg/m3)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Acetaldehyde
Formaldehyde
Front Loader
Bulldozer
Hyster Lull-A
Upwind
Downwind
Front Loader
Bulldozer
Hyster Lull-B
Upwind
Downwind
Front Loader
Bulldozer
Hyster Lull-B
Upwind
Downwind
Monitoring Location (Day 1 - 3, left to right)
Acetaldehyde = 0.45 µg/m3 Formaldehyde = 0.077 µg/m3



<u>Concentrations of Toxic Metals in $PM_{2.5}$ Collected by Operating HDD Equipment:</u>

Results indicate that the concentrations of toxic metals observed in ambient $PM_{2.5}$ samples are increased when nonroad equipment is operating. Metals such as nickel, vanadium, and iron are higher in samples collected in-cabin or near the perimeter of monitoring sites. These metals vary by location.
Initial results from x-ray fluorescence and inductively coupled plasma mass spectrometry indicate that the concentrations of toxic metals observed in the $PM_{2.5}$ samples collected in an operating equipment cab or near the site perimeter are altered. These concentrations vary across sites and may present adverse health impact risks for workers and nearby residents. As shown in the figures below, the concentrations of several toxic metals vary between sampling locations (MEL= Maine Lumberyard; KSC= NH Construction Site; and NY= NY Construction Site). Additionally, as shown in the following figures, the concentration of vanadium exceeds the ACGIH recommended occupational exposure limit for an eight-hour workday (50 ng/m^3). If this exposure was repeated, individuals are at risk of developing adverse health outcomes at this concentration.



Metal Content $PM_{2.5}$
100%
80%
60%
40%
20%
0%
-20%
MEL Near Worker
MEL Mill Cab
KSC Perimeter #2
KSC VRL (A)
KSC VRL (B)
NY2 Excavator
NY PC100
NY1 Excavator
Sample Location
Nickel
Lead
Arsenic
Zinc
Copper
Manganese
Vanadium

Vanadium Concentration in $PM_{2.5}$