

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

Interim Report
June 9, 2003

**Northeast States for Coordinated Air Use Management
(NESCAUM)**

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I. Initial Study Overview and Findings

A. BACKGROUND

This study was conducted by the Northeast States for Coordinated Air Use Management¹ (NESCAUM), 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, review 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 across the region. 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; therefore, complete data are not yet available from all sites evaluated. **This interim report provides preliminary conclusions and a summary of selected results available from three of the five sites evaluated** during the past twelve months of active fieldwork. A final report and conclusions will be forthcoming.

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. At this time a comprehensive presentation of this work is not available; however, initial speciation results are presented later in this interim summary.

¹ a nonprofit association of the eight air quality agencies of the Northeast states

B. INITIAL FINDINGS

Note: to view sample interim study results that support these findings, please refer to Appendix C.

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 1-16 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 µg/m³ to over 660 µg/m³. 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 estimated to exist at levels that pose risk of chronic inflammation and lung damage in exposed individuals.

Diesel particulate matter concentrations were shown to exceed the established reference concentration (5 µg/m³) in both in-cabin and the perimeter samples². 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.

At this time, complete elemental and organic carbon and metal speciation analyses are not available for this work. However, recognizing the significant contribution of diesel exhaust to ambient PM_{2.5}, it is possible to estimate the potential range of contribution of

² Assuming based on USEPA data, that diesel particulate matter constitutes between 6 and 36% 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.

the nonroad equipment diesel particulate matter emissions to the total average PM_{2.5} concentration recorded at each site analyzed to date. It is estimated that nonroad equipment activities at the three sites analyzed thus far result in diesel particulate matter exposures for workers and nearby residents ranging from 1 µg/m³ to 230 µg/m³.

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

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. 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.

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 1 in 1 million cancer health benchmarks across the country³. 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. 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.

Initial results 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 risk(s) 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.

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 interim 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 operators and at the perimeter of the worksite. The in cab samples were collected to characterize occupational exposures for equipment operators⁴. The worksite perimeter samples⁵ (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, 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 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.

Carbonyl Analyses (EPA Method TO-11):

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.

⁴ Using 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.

Volatile Organic Compound Analysis (EPA Methods TO-17-UMASS-Lowell and TO-15-ERI):

In cabin exposures 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, 8 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 by ERI.

Organic and Elemental Carbon Analysis (NIOSH Method 5040):

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 cm²) is removed and placed 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 CO₂ then reduced to methane (CH₄) for detection by a flame ionization detector. The temperature is reduced to 550 °C and the atmosphere is changed to 2% O₂ 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% O₂ 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}.

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. Since 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.

Estimation of number of workers using heavy equipment

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 1 (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 segments. Columns 3, 4, and 5 of Table 1 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.

Table 1. Ratio of Equipment to Employees in Three Counties

<i>Description</i>	<i>8 State</i>	Equipment counts per employee		
	<i>Employees</i>	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

The combination of equipment counts per employee and employees in each industry category can be combined to estimate the equipment operational in the 8-State NESCAUM region. Since 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.

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 1100 hours or about 20 – 50% of an average 8-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. So the total equipment counts calculated above underestimates 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 interim 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 exposure⁶, the US EPA recently finalized a health-protective **reference concentration of 5 $\mu\text{g}/\text{m}^3$** for diesel particulate matter (DPM)⁷. The MSHA has established an interim allowable occupational exposure standard⁸ for diesel particulate matter of **400 $\mu\text{g}/\text{m}^3$** this standard will drop to a final allowable exposure limit for this worker population of **160 $\mu\text{g}/\text{m}^3$** 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 EC/OC data are not yet available for this project. These data will be forthcoming; however, in the interim by using previous inventory analyses completed by the EPA, one can assume that DPM constitutes a minimum of 6 % of the national total ambient inventory for $\text{PM}_{2.5}$, 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% of the $\text{PM}_{2.5}$ mass⁹.

When considering the non-cancer health effects associated with exposure to $\text{PM}_{2.5}$ mass in general, the current **National Ambient Air Quality Standard of 65 $\mu\text{g}/\text{m}^3$ (24-hour)** established by the United State Environmental Protection Agency may be 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 $\mu\text{g}/\text{m}^3$** and the ACGIH,

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.

has established a **threshold limit value of 3000 $\mu\text{g}/\text{m}^3$** . The MSHA standard of **400 $\mu\text{g}/\text{m}^3$** may also be used.

When evaluating cancer effects, the United States Environmental Protection Agency 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 (eg. 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 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 non-road 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. The final report will more fully characterize the scope and magnitude of exposure and policy challenges presented by nonroad equipment activities.

Appendix A: Summary Testing Matrix¹⁰

Date	Location	In Cabin Monitoring (3 - 5 pieces) EC/OC ¹¹	Upwind Site – Perimeter #1 (~300ft X 300 ft site) EC/OC	Downwind Site – Perimeter #2 (~300ft X 300 ft site) EC/OC
July 2002 <i>through</i>	Roadway Construction Keene, NH	Respirable cyclone (PM ₄) @ 4.2 liters/minute	Respirable cyclone (PM ₄) @ 4.2 liters/minute	Respirable cyclone (PM ₄) @ 4.2 liters/minute
June 2003	Forestry Operations Carmel, ME Building Construction New York City Agricultural Operations Brattleboro, VT Roadway Construction Manchester, NH	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	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)

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. 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 will be integrated with real-time monitoring results once all site data are available. 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 (PM₄). Real-time monitoring was also conducted, as detailed above, to quantify respirable particulate matter (PM_{2.5}), diesel soot (PM₄), and site weather conditions.

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

Appendix B: Health Effects Database Summary Sheets

Acetaldehyde

CAS: 75-07-0

Chemical Formula: CH₃CHO

Molecular Weight	44
RfC	9x10 ⁻³ mg/m ³
RfD	No Data
EPA Unit Cancer Risk Value 1 :1,000,000	5x10 ⁻⁴ mg/m ³
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/m ³ 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		
<i>Potential Human Carcinogen</i>	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/m ³ 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: C₆H₆

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, dermatitis, 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		
<i>potential occupational carcinogen</i>	Leukemia	

NOAEL www.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/m ³
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/m ³
	Item # 14=Mouse-47ppm (decreased WBC Count)	
	Item# 85=Rat-88ppm (leukopenia)	
	Item #131=Rat-960ppm (30% depression of evoked electrical 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/m ³
Occupational Limits	
15 - minute STEL	5 ppm
OSHA PEL 8-hour TWA	1 ppm (Action level- .5ppm)
ACGIH TLV	2 ppm, 4.4 mg/m ³ 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	CNS Depression bronchiolar adenomas, neoplasms granulosa cell tumors,(females) acinar cell carcinomas of mammary gland, testicular atrophy
Central Nervous System	Drowsiness, headache, fatigue	
Respiratory System	Irritation Nose, Dryness Irritation, respiratory paralysis	
Reproductive System	Teratogenic Reproductive Effects	
Skin (liquid exposure)	Frostbite, Irritation	
Reproductive		
Developmental <i>potential occupational carcinogen</i>	Hematopoetic Cancer	

NOAEL www.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/m ³
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/m ³

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: CH₂O

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	
<i>potential occupational carcinogen</i>	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/m ³ 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/m ³
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
<i>Potential Human Carcinogen</i>	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/m ³ NOAEL/HEC: 0.144 mg DPM/m ³	0.96 Ishinishi <i>et al.</i> (1988) (HD)

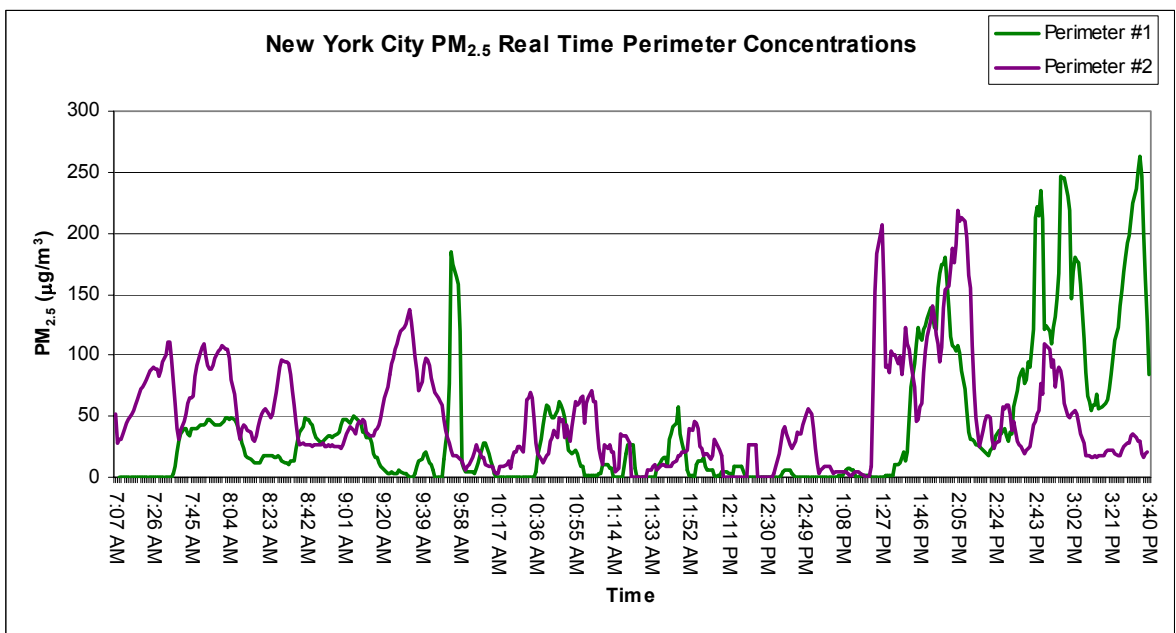
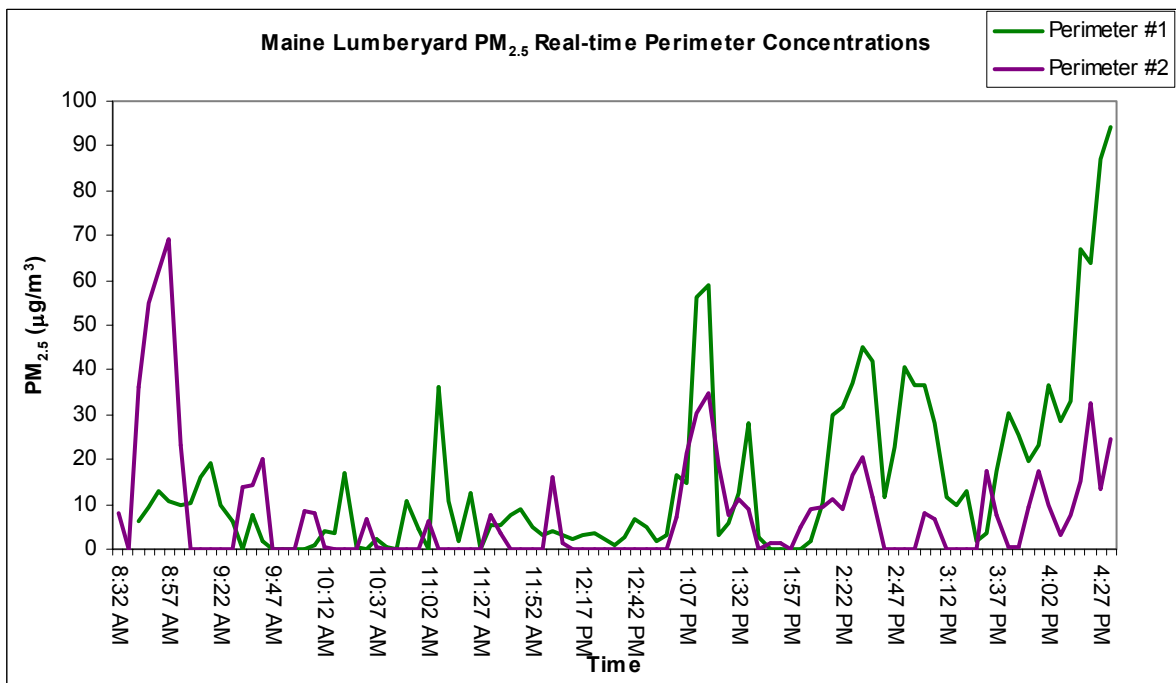
Sampling Methods OSHA	Primary
Method No.	ID-196 (Carbon Black in Workplace Atmospheres)
Media:	Samples are collected on polyvinyl chloride (PVC) filters. 37mm. 5.0-micrometer pore size
Max Volume (TWA)	480 to 960 liters
Max Flow (TWA)	2 liters/minute
ANL 1:	gravimetric
CLASS	Fully Validated

Appendix C: Interim Summary Data from Three of Five Monitored Sites

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 (shown in Figures 1 and 2). 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.

Figures 1 and 2. Real-time PM_{2.5} concentrations at the perimeter of nonroad equipment site.



Daily Minute-to-Minute Exposure Diesel Particulate Matter (diesel soot):

As shown in Figures 3 and 4 below, diesel soot concentrations (measured as black carbon –BC) vary throughout the day, arguably due to nonroad equipment activity on the site. Future analyses will compare these results to observations recorded in the time-activities diaries for each site. Note the vast difference, as shown in Figures 1 and 2 previously, between the Maine site and New York City. Recalling that the reference concentration for diesel particulate matter is $5 \mu\text{g}/\text{m}^3$, it is possible to identify a potential overexposure by averaging the results in New York City around the construction site assessed.

Figure 3: Black carbon concentrations measured at Maine Lumberyard

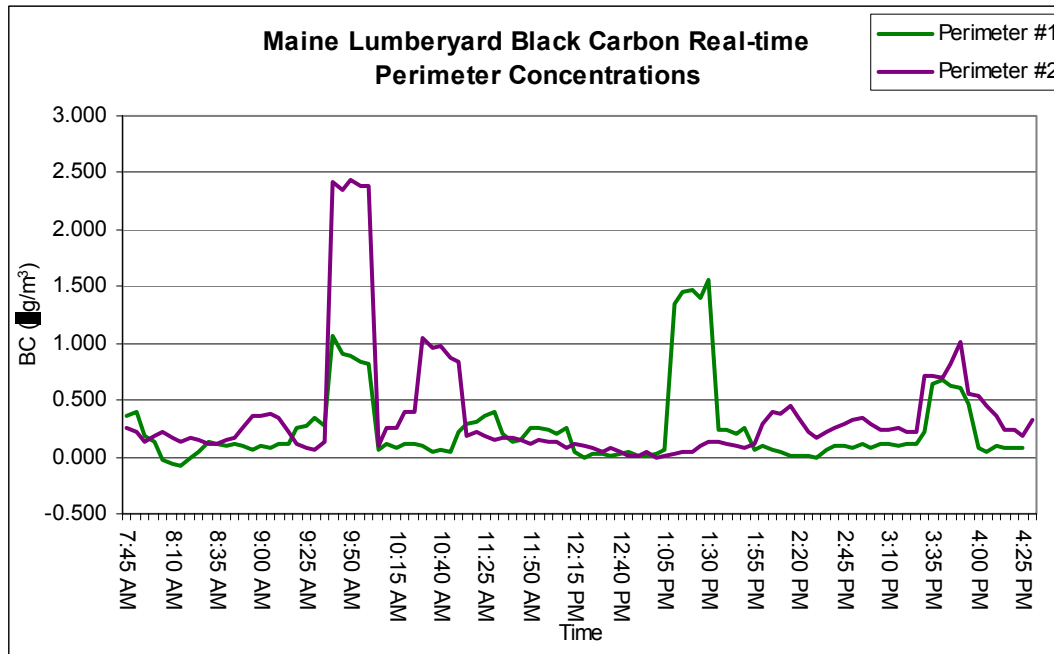
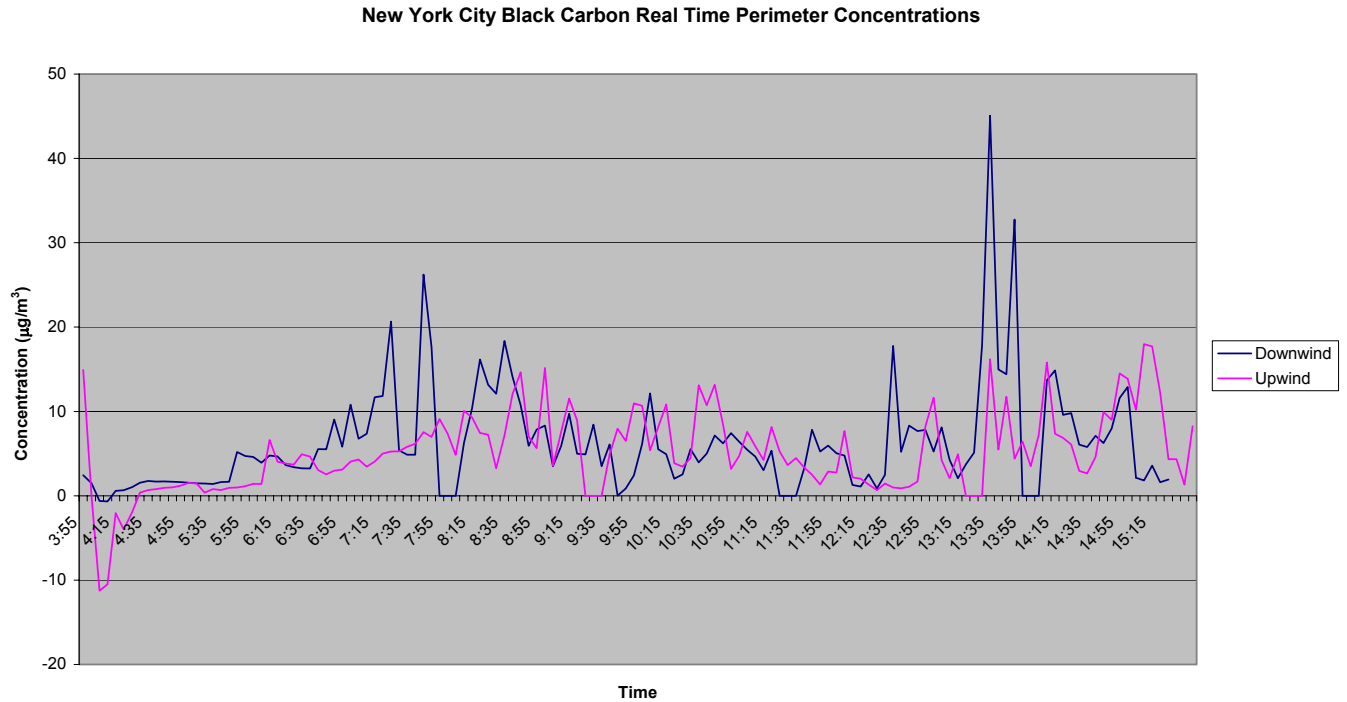


Figure 4. Black carbon concentrations measured at New York City Construction Site



Daily Average Exposures to PM_{2.5} and The Impact of Work on Individual Exposure

Figure 5 illustrates the daily average exposure to PM_{2.5} on a construction site in New Hampshire. The concentrations of PM_{2.5} monitored over the course of each consecutive monitoring day are in bold print in the far left column of the table. Estimated diesel particulate (DPM) exposures for each of the eight-hour samples are then calculated and presented in the second and third column. If the reference concentration for DPM was exceeded during the eight-hour day, the value is shaded. In the fourth column, a 24-hour exposure is calculated in order to determine the potential impact of nonroad construction work on an individual’s daily exposure to PM_{2.5}. In order to estimate the 24-hour exposure, the individual or perimeter concentration measured over eight-hours (shown in the first column) is averaged for the remaining sixteen hours of the day at average ambient PM_{2.5} concentrations for the area as reported by the state air quality control agency. If the 24-hour integrated exposure is greater than the USEPA National Ambient Air Quality Standard (NAAQS) of 65 µg/m³, then the value is shaded. In the remaining two columns of the table, the 24-hour DPM exposure concentration is estimated, again if the reference concentration is exceeded, the column is shaded. These calculations will be completed for all sites evaluated during this project.

Figure 6 graphically illustrates the estimated low or high contribution of DPM to the measured PM_{2.5} for the Day 1 New Hampshire construction site samples. This figure also illustrates the magnitude of exceedance above the established reference concentration for diesel particulate matter.

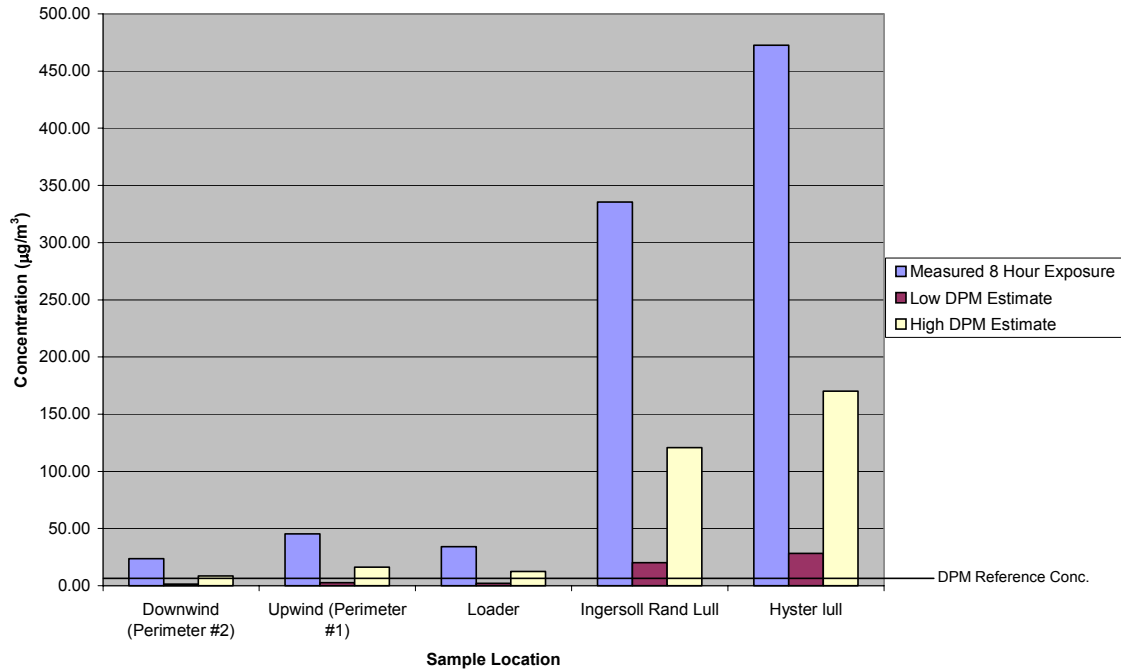
Figure 5. NH Construction Activity PM_{2.5} Integrated Sampling Results

Sampling Location	Monitored 8-hour	Estimated Low DPM		Estimated High DPM		Estimated	Estimated Low	Estimated High
	Average PM _{2.5} Conc. (µg/m ³)	Conc. (µg/m ³) RfC = 5 µg/m ³	RfC =	Conc. (µg/m ³) RfC = 5 µg/m ³	RfC =	24-hour Average* PM _{2.5} Conc. (µg/m ³) NAAQS = 65 µg/m ³	DPM Conc. (µg/m ³) RfC = 5 µg/m ³	DPM Conc. (µg/m ³) RfC = 5 µg/m ³
Day 1								
Bulldozer	N/D	N/D		N/D		N/D	N/D	N/D
Downwind (Perimeter #2)	23.79	1.43		8.56		17.26	1.04	6.21
Upwind (Perimeter #1)	45.19	2.71		16.27		24.40	1.46	8.78
Loader	34.16	2.05		12.30		20.72	1.24	7.46
Ingersoll Rand Lull	335.50	20.13		120.78		121.17	7.27	43.62
Hyster lull	472.62	28.36		170.14		166.87	10.01	60.07
Day 2								
Upwind (Perimeter #1)	15.93	0.96		5.73		14.64	0.88	5.27
Downwind (Perimeter #2)	N/D	N/D		N/D		N/D	N/D	N/D
Lull	660.89	39.65		237.92		229.63	13.78	82.67
Front loader	32.29	1.94		11.62		20.10	1.21	7.23
Bulldozer	8.20	0.49		2.95		12.07	0.72	4.34
Day 3								
Bulldozer	42.64	2.56		15.35		23.55	1.41	8.48
Upwind (Perimeter #1)	14.44	0.87		5.20		14.15	0.85	5.09
Front Loader	62.89	3.77		22.64		30.30	1.82	10.91
Lull	168.10	10.09		60.52		65.37	3.92	23.53
Downwind (Perimeter #2)	25.10	1.51		9.04		17.70	1.06	6.37

*Assumes 16-hr ambient average concentration is 14 µg/m³

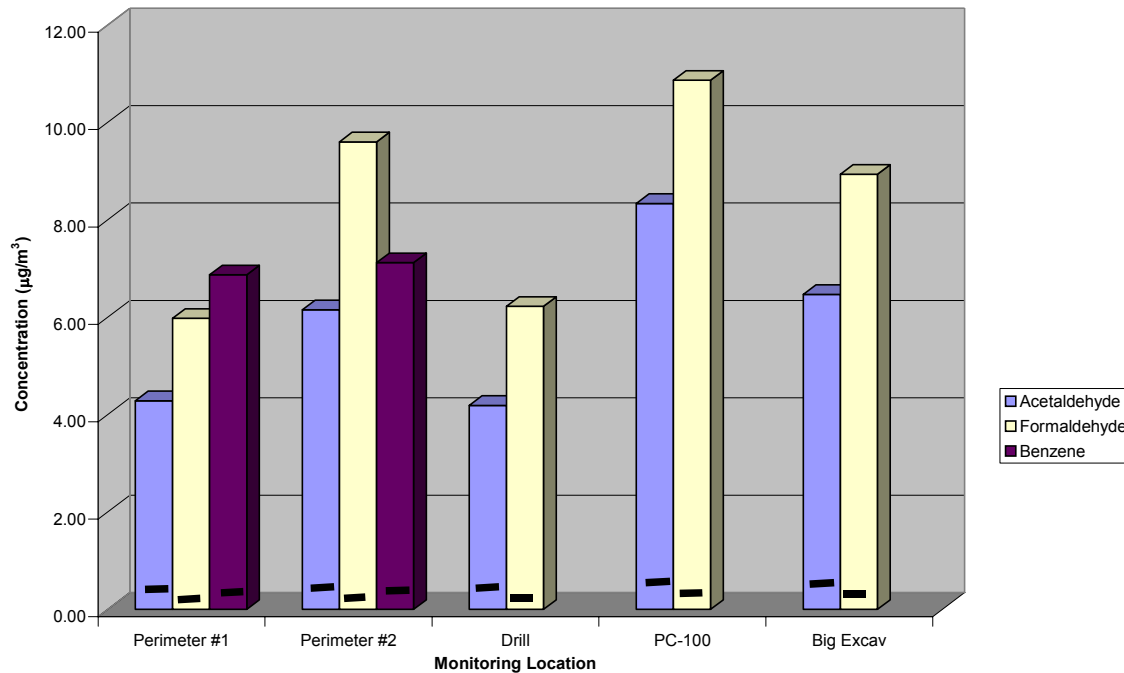
Shaded values reflect exceedance of diesel particulate matter reference concentration (RfC) or the PM_{2.5} National Ambient Air Quality Standard (NAAQS)

Figure 6. NH Construction Site Monitored PM_{2.5} Concentrations



Daily Exposures to Gaseous Toxicants:

As shown in Figure 7 below the monitored concentrations for acetaldehyde, benzene, and formaldehyde exceed conservative risk screening thresholds for cancer. The x-axis for this figure indicates the monitored concentration in mg/m³ and the y-axis identifies the monitoring location on the New York City construction site. The black line on each compound-specific column indicates the one in one million risk screening concentration. Future analyses will compare these monitored values with measured ambient concentrations for these same compounds to quantitatively assess the impact of nonroad equipment activity on measured gaseous pollutants. Additionally, benzene in cab monitoring result will be integrated with these data.



Concentrations of Toxic Metals in PM_{2.5} Collected by Operating HDD Equipment:

Initial results 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 risk(s) 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.

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 operating equipment cab or near the site perimeter are altered. These concentrations vary across sites and may present adverse health impact risk(s) for workers and nearby residents. As shown in Figure 8 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 Figure 9, the concentration of vanadium exceeds the ACGIH recommended occupational exposure limit for an eight-hour workday (50 ng/m³). These data will be integrated with additional analyses from the remaining sites and will be more completely summarized in the final report for this project.

Figure 8. Metal Content PM_{2.5}

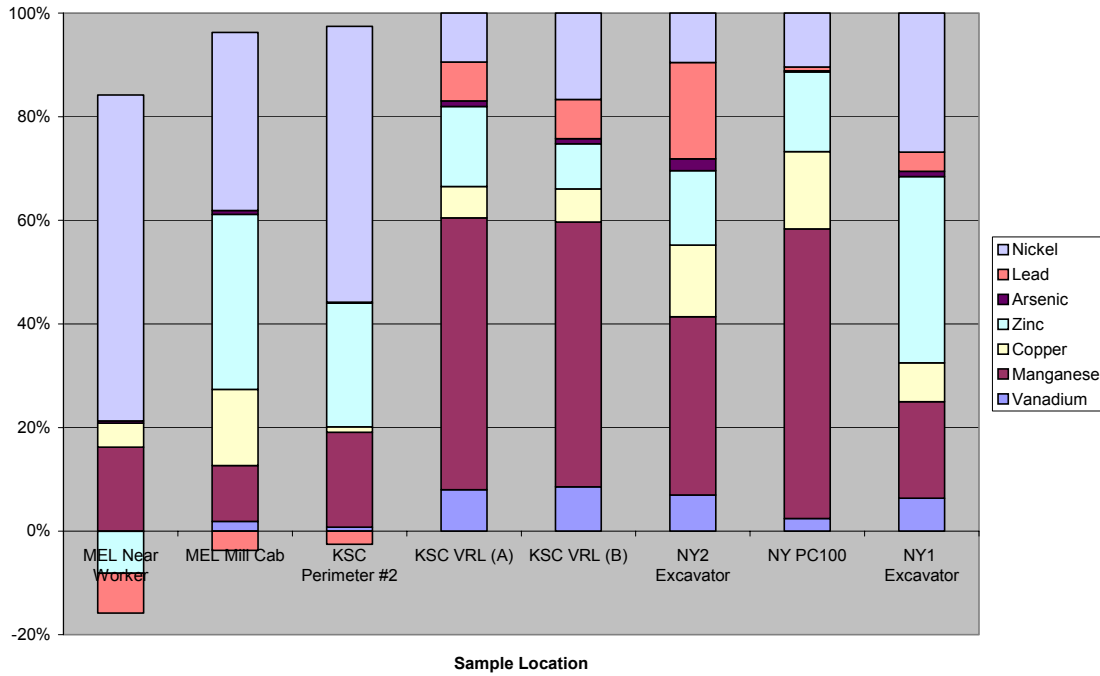


Figure 9. Vanadium Concentration in PM_{2.5}

