June 28, 2016

Mr. Gregory Jenkins
Executive Director
Somerville Arts Council
City of Somerville
50 Evergreen Avenue
Somerville, MA 02145

Subject: Ambient Air Quality at Planned ARTfarm Site in Somerville, MA

Dear Mr. Jenkins:

The City of Somerville Arts Council retained Tufts University to measure and evaluate air quality at the planned Somerville ARTfarm for Social Innovation site, located at 10 Poplar Street. The site was formerly used for waste transfer and is being redeveloped as a creative commons designed to foster community betterment. Due to the site's close proximity to McGrath Highway (Route 28), the Arts Council expressed concerns that the busy thoroughfare might lead to excessive exposure to air pollutants released from vehicular traffic.

The main objectives of this project were to: 1) provide a baseline understanding of the air quality conditions at the proposed ARTfarm site, and 2) provide recommendations to the design team on how to reduce exposure. To accomplish this, researchers from Tufts University measured air pollutants at ARTfarm over 37 days from January 12-February 18, 2016. The study focused on measuring locally elevated ultrafine particulate (UFP; <100 nanometers diameter) concentrations, but benefited from having a suite of instruments available to measure additional pollutants.

In general, pollutant concentrations were elevated above baseline during weekday days, often during rush hour periods. The peaks of many pollutants overlapped with other pollutant peaks, but that was not always the case. Much of the time, if one pollutant was increasing the other pollutants were also increasing. Some of the time, though, an increase in one pollutant did not correspond to increases in other pollutants. Wind speed and direction played a major role in the pollutant concentrations measured at ARTfarm. Calm and very low wind speeds typically resulted in elevated concentrations of all pollutants measured. At higher wind speeds, wind direction became more important in determining the air quality at the site.

Monitoring Study Design

Tufts researchers deployed their mobile laboratory (Tufts mobile Air Pollution monitoring Laboratory; or TAPL) to ARTfarm for continuous monitoring. The TAPL was positioned just inside the ARTfarm property line along Poplar Street, halfway between McGrath Highway and Linwood Street. All instruments were connected to a sampling tube that drew air from an inlet at the top of the TAPL. Instruments were powered via an electrical connection nearby. Figure 1 shows the setup of the monitoring equipment inside the TAPL.

Figure 1: Air monitoring equipment setup inside TAPL.

Sampling instruments employed in the study included:

- A chemiluminescence analyzer (Thermo Scientific 42i) to measure NO, NO_2 and NO_X;
- A laser photometer with $PM_{2.5}$ selective inlet (TSI Sidepak AM510) to measure $PM_{2.5}$;
- A condensation particle counter (CPC; TSI Model 3775 and TSI Model 3783) to measure particle number concentration (PNC; a proxy for UFP);
- An aethalometer (Magee Scientific AE-16) to measure black carbon (BC);
- A photoelectric aerosol sensor (EcoChem Analytics PAS2000) to measure particle-bound polycyclic aromatic hydrocarbons (PAH);
- A gas filter correlation analyzer (Thermo Scientific 48i-TLE) to measure carbon monoxide (CO) [1]; and
- A fully integrated weather station (Davis Vantage Vue) to measure meteorological conditions.

[1] The CO analyzer was removed from service at the start of monitoring after failing the calibration step multiple times.

Instruments were calibrated onsite prior to the start of monitoring at ARTfarm. The gas analyzers were calibrated against reference gases at specified concentrations, including zero air (i.e., air free of the monitored gases). The Sidepak was calibrated with a zero-particle filter. The CPCs underwent a flow rate and zero-concentration check prior to installation. All instruments have completed routine annual calibration with the equipment manufacturer. Data collection began at 12:30 PM on Tuesday, January 12, 2016, and finished at 5:30 PM on Thursday, February 18, 2016. The sampling period was designed to provide up to four weeks of continuous coverage for each pollutant of interest. Measurements were taken every 10 seconds to every minute for different instruments over the sampling period. Data were downloaded from the instruments and compiled in an MS-Excel spreadsheet. Data analysis was completed with the statistical package R (version 3.2).

Meteorological Data Collected by the National Weather Service

Raw 5-minute measurements of wind speed and direction (previous 2-minute average) were obtained from the National Weather Service's weather station at Logan International Airport for use in analyzing the impact of various wind conditions on pollutant concentrations at ARTfarm. These data were compared to data collected with the on-site Vantage Vue to ensure the weather data from Logan were representative of the conditions at ARTfarm. Logan data was preferred over on-site data due to equipment malfunctions with the Vantage Vue during the first two weeks of the monitoring campaign. Comparisons between the two weather stations showed similar meteorological trends, including wind speed and direction.

Data Processing and Reduction

Tufts researchers examined the ARTfarm data to eliminate outlying values judged to result from sampling and instrumentation errors. The method used to measure particulate matter depends on the relationship between the particulate matter concentration in air and the measured light attenuation. An adjustment factor of 0.6 was applied to the $PM_{2.5}$ measurements to account for the difference between the particle density used to calibrate the instrument versus the typical average composition of particles in the metropolitan Boston area (Masri *et al*., 2015). The ARTfarm data were then time-averaged over hourly and longer periods (up to 24 hours). In constructing each one-hour average, 50% data coverage was required for validity, *e.g.*, at least 30 of the 60 possible observations over each individual hour for an instrument recording data every minute were required to develop a one-hour average (otherwise, no hourly average was calculated).

Air Quality at ARTfarm (Winter Case)

Air pollutant measurements collected over the study period are depicted in a sequence of weekly time series plots (Figures 2-7). Pollutant concentrations were adjusted to fall within the concentration range of 0 to 100 on the plot in order to plot all pollutants in the same figure. The adjustment factor (if any) and units for each pollutant are shown in the plots' legend. For example, measured PNC, with units of particles/cm^3, was divided by 1,000 (shown as #/cm3/1000 in the plots' legend). The start of each week in the plots begins on Sunday. Grey bars represent rush-hour times during the week on non-holiday days (i.e., morning rush = 6:00-9:00 AM, evening rush = 4:00-7:00 PM). Midnight falls on the date tick mark.

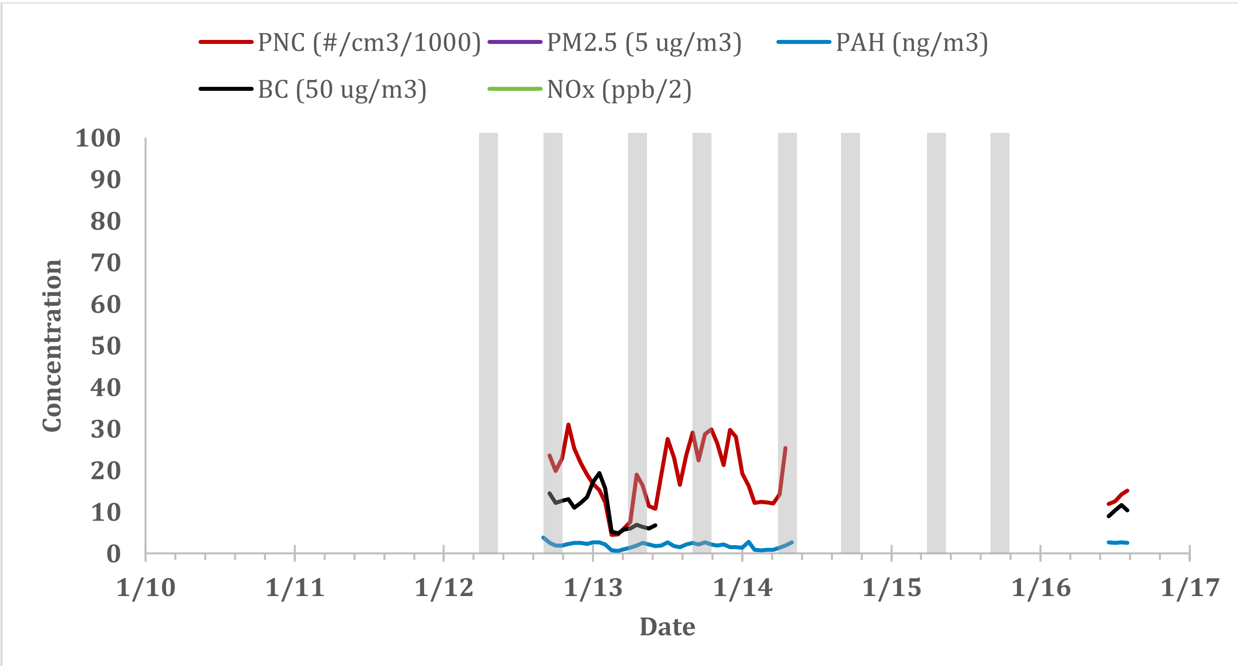

Figure 2: Week 1 – monitoring began Tuesday, January 12. Concentrations were relatively low during periods with data, however numerous equipment problems prevented measurements of most pollutants.

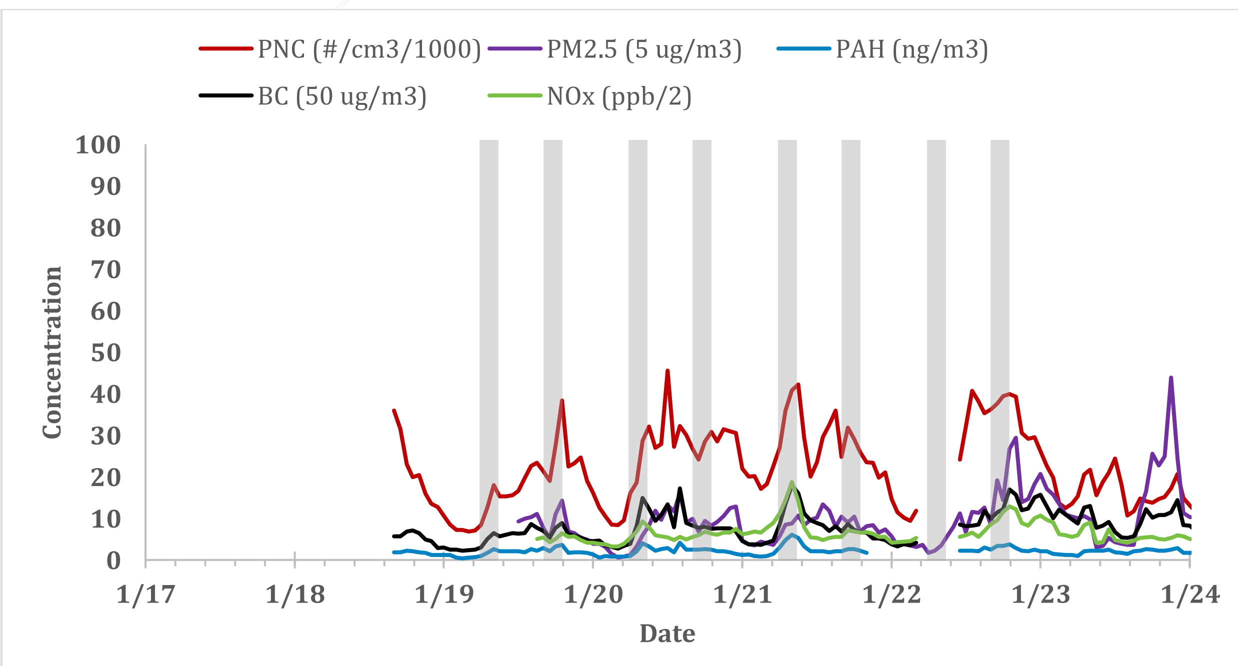

Figure 3: Week 2 – concentrations were low relative to peak concentrations. Monday, January 18 was a national holiday.

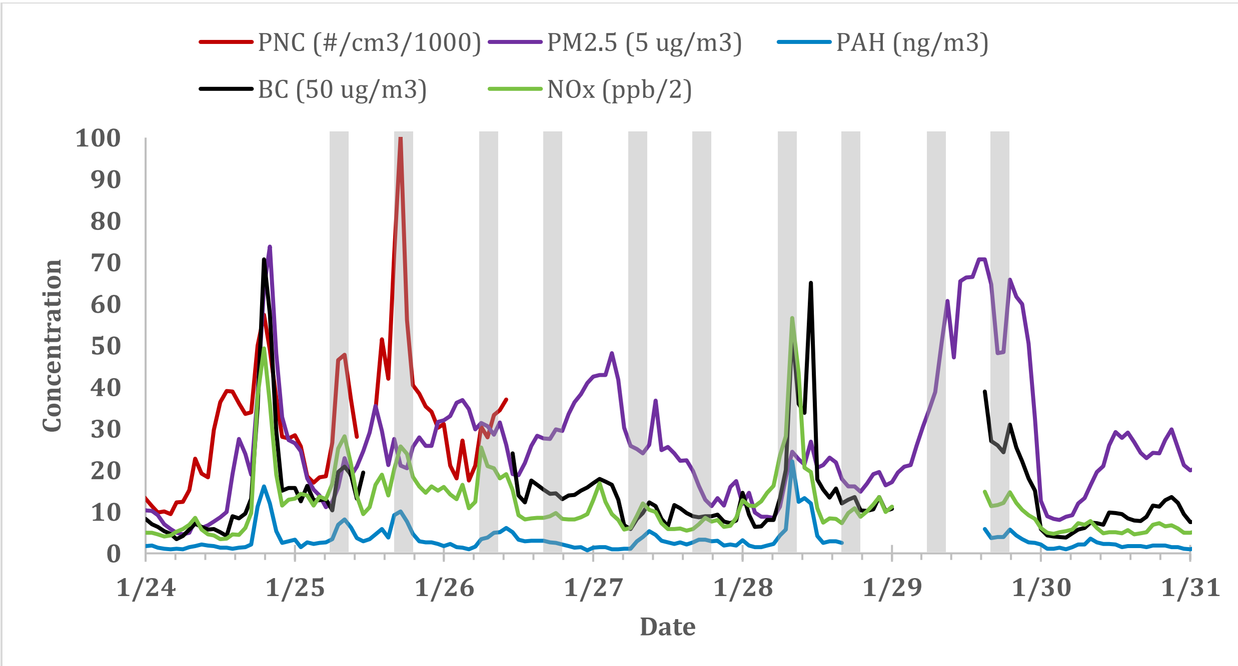

Figure 4: Week 3 – concentrations of multiple pollutants increased relative to the previous two weeks. Monday, January 25 recorded the highest PNC level at 100,000 particles/cm^3, which occurred between 4:00-5:00 PM. This level is very high, even for near roadway locations.

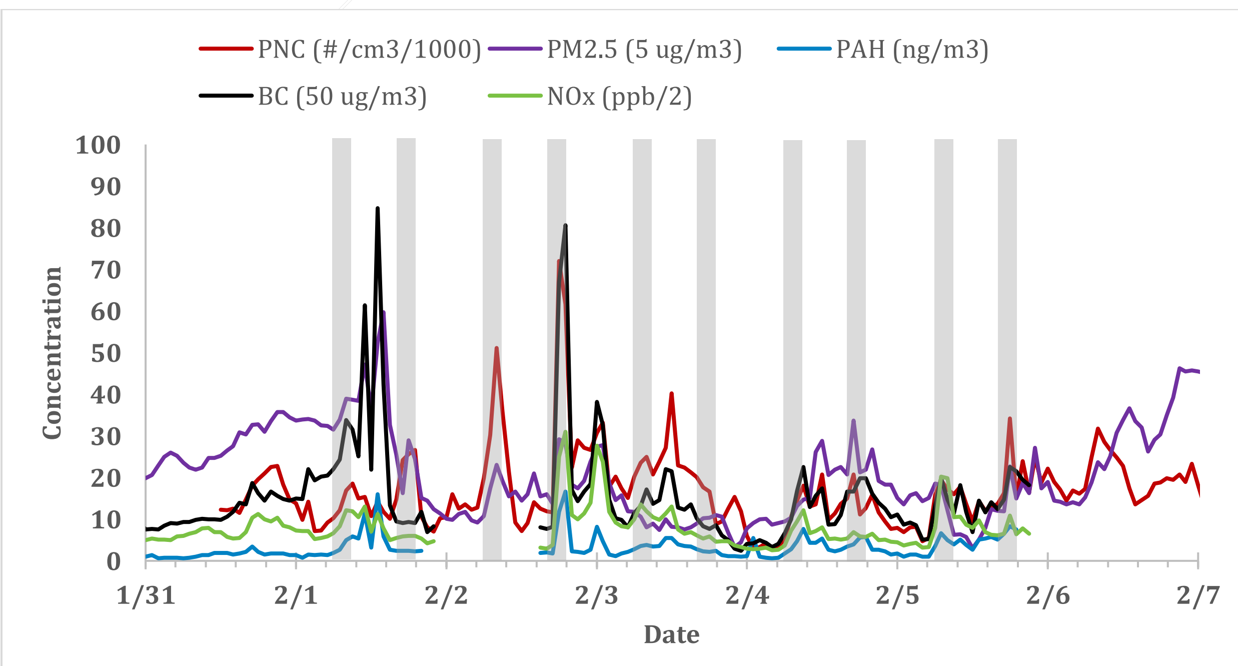

Figure 5: Week 4 – there were higher peaks in the first half of the week. Monday, February 1 recorded the highest BC level at 1.7 µg/m^3, which occurred between 12:00-1:00 PM. Tuesday evening also saw substantially elevated concentrations of all pollutants.

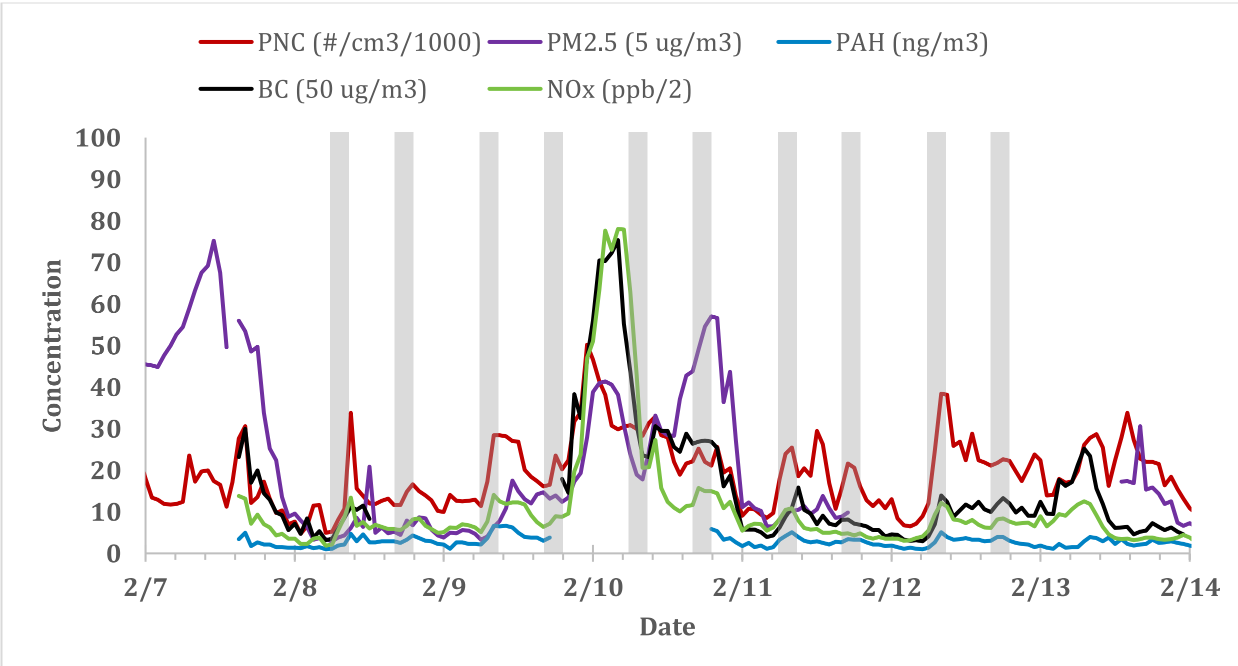

Figure 6: Week 5 – concentrations of $PM_{2.5}$ were elevated over the weekend of February 6-7, with concentrations reaching near the peak Sunday afternoon. Wednesday had elevated concentrations of all pollutants with winds coming from the south at less than 10 mph.

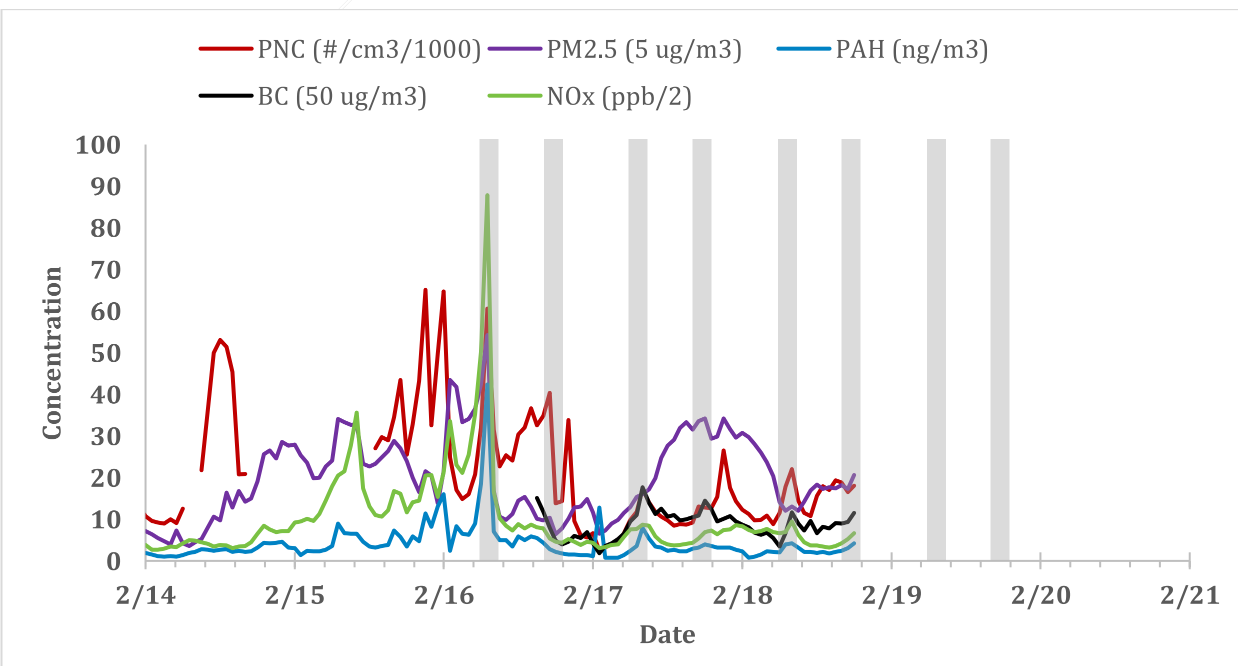

Figure 7: Week 6 – monitoring ended Thursday, February 18. Highest recorded PAH and NO_X levels occurred Tuesday, February 16 between 6:00-7:00 AM. The PAH concentration was 43 ng/m^3 and NO_X concentration was 176 ppb. Monday, February 15 was a national holiday.

During many of the hours if one pollutant was increasing other pollutants were also increasing, likely due to pollutants originating from the same source. In some cases, though, one or more pollutant was increasing while others were not. We have not been able to identify the reason behind the diverging pollutant concentrations. Doing so would likely require additional data collection and analysis. One possible reason for a diverging trend, for example when PNC was increasing but BC was not, is a difference in the local fleet of vehicles. A higher proportion of gasoline-powered vehicles would generate less BC than would a higher proportion of diesel-powered vehicles, but PNC would be elevated in both cases.

Qualitatively, the temporal patterns of concentrations are similar across all pollutants measured. Most of the diurnal spikes are observed in the day, during rush hour periods (highlighted), although there are outliers. Many of the peaks overlap with other pollutant peaks, but that was not always the case. Rush hour periods were typically associated with substantial increases in PNC, as would be expected. Wind speed and direction impacted the height of these peaks as shown in the plots that follow. Comparative summaries of the measured air pollutant concentrations are provided in Table 1 and 2. These tables are constructed from data collected only during the sampling period at ARTfarm. Count represents the number of hours available for data analysis.

Table 1: 1-Hour average concentrations at ARTfarm for particle-based pollutants.

	PNC (particles/cm^3)	$PM_{2.5}$ (µg/m^3)	Black Carbon (µg/m^3)	PAH (ng/m^3)
Count (hours)	639	683	576	670
Average	21,000	4.1	0.25	3.0
Min	2,500	0.1	0.04	0.4
Max	100,000	15	1.7	43

Table 2: 1-Hour average concentrations at ARTfarm for gas-based pollutants.

	NO (ppb)	NO_2 (ppb)	NO_X (ppb)
Count (hours)	647	647	647
Average	5.37	14.0	19.5
Min	0.14	3.09	3.70
Max	134	51.1	176

Two of the pollutants measured fall under the U.S. Environmental Protection Agency's (EPA) established National Ambient Air Quality Standards (NAAQS) designed to protect public health:

- NO_2, with NAAQS of 100 parts per billion (ppb) over a 1-hour averaging period and 53 ppb over an annual averaging period; and
- $PM_{2.5}$, with NAAQS of 35 µg/m^3 over a 24-hour averaging period and 12 µg/m^3 over an annual averaging period.

The highest daily 1-hour average concentrations of NO_2 measured at ARTfarm – on average 14 ppb and at most 51 ppb – are well below the NAAQS of 100 ppb. Daily average concentrations of fine particulate are all below the NAAQS of 35 µg/m³, with the highest value observed at ARTfarm more than a factor of two lower.

Wind speed and direction had a major influence on the pollutant levels measured at ARTfarm. Figure 8 details the wind variability in both speed and direction over the entire monitoring duration. Data were broken out by type of day (i.e., weekday vs. weekend) and time of day (i.e., day vs. night). In the figure each color represents a range of wind speeds, while wind direction is represented by the position of each wedge. A wedge with the outer edge pointing north represents winding coming *from* the north. The thickness of each color within a wedge represents the percentage of time those wind speeds are from that direction. For example, 5% of wind from the west during a weekday day is blowing at 15-20 mph. Mean wind speed at ARTfarm was consistent regardless of the type of day or time, with an overall mean of 12.7 mph. Close to half of winds originated from the west to northwest, approximately 50% of the time during the week, and approximately 40% of the time during the weekend. Wind speeds from these directions were among the highest. The lowest wind speeds and least frequent wind directions occurred in the east to south quadrant. This trend was consistent regardless of type of day or time, except weekend days where north to east winds were least frequent and had the lowest speeds.

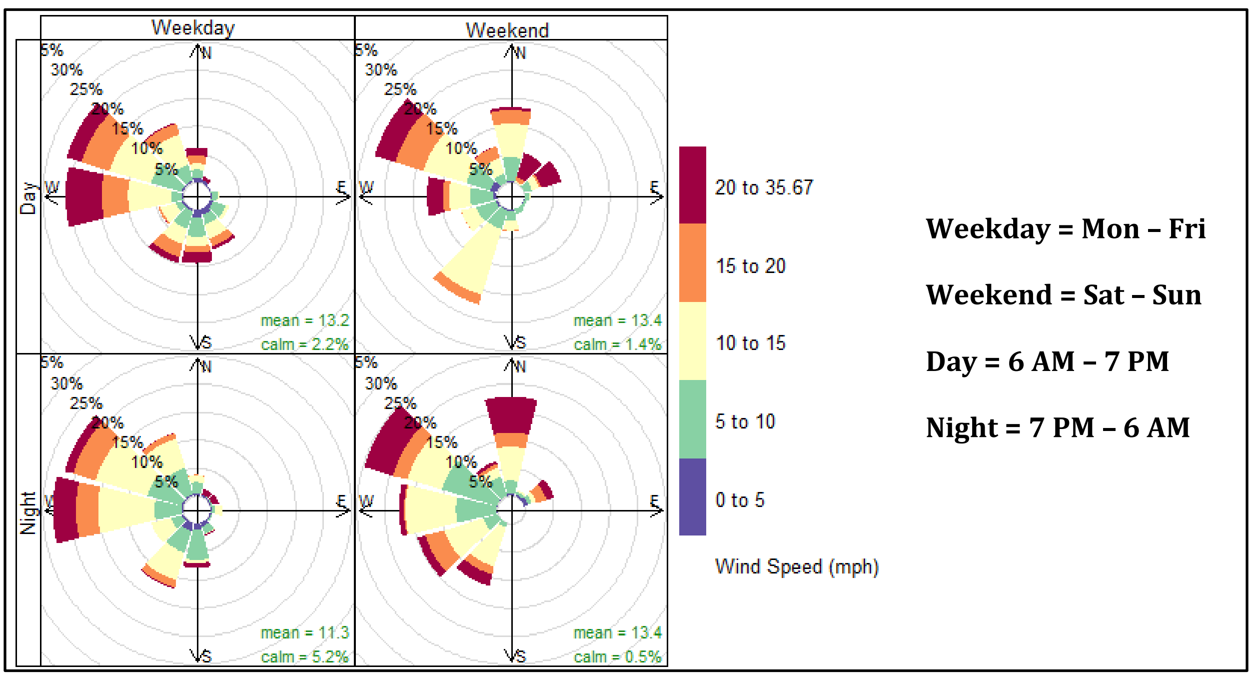

Figure 8: Wind rose during monitoring period at ARTfarm. Wind speed and direction data are from the National Weather Service's weather station at Logan International Airport. Data are composed of 5-minute measurements. Wind roses are broken out by type of day (i.e., weekday or weekend) and time of day (i.e., day or night). Mean wind speed during the entire monitoring campaign was 12.7 mph (max = 35.7 mph).

Figures 9-15 merge wind speed and direction and measured pollutant concentrations into a single plot. Similar to the wind rose in Figure 8, each wedge within the plot represents the direction from which the wind is blowing. If the wedge is pointed out towards north, then winds are coming from the north. Each plot contains 36 possible wind direction wedges. As one moves further out from the center of the plots wind speed increases. Wind speed bins are sized at two mph, meaning all points within a two mph range fall into the same bin for a given wind direction. Each bin contains a minimum of two data points; all data points within a bin are averaged to generate a single colored box representing the mean concentration of a specified pollutant for a given wind speed and direction. Since the four main categories used to separate out the data (i.e., weekday day, weekday night, weekend day, and weekend night) do not contain the same number of hours, weekends will contain fewer data points than weekdays. Weekend nights contain the fewest data points.

In general, concentrations were higher at ARTfarm during weekday days (i.e., Mon-Fri 6 AM – 7 PM) than any other time, as would be expected due to increased traffic. Low wind speed, regardless of wind direction, was also correlated with higher concentrations among all pollutants measured. Lower wind speeds mean lower turbulence, which reduces mixing in air. Pollutants can be thought of as accumulating during this type of wind condition (in most cases), especially during winter months when vertical air mixing is also minimized and the atmosphere is usually more stable. As wind speeds increased, higher concentrations of most pollutants were generally correlated with winds from the southwest to southeast, due to the transport of pollutants originating from further away.

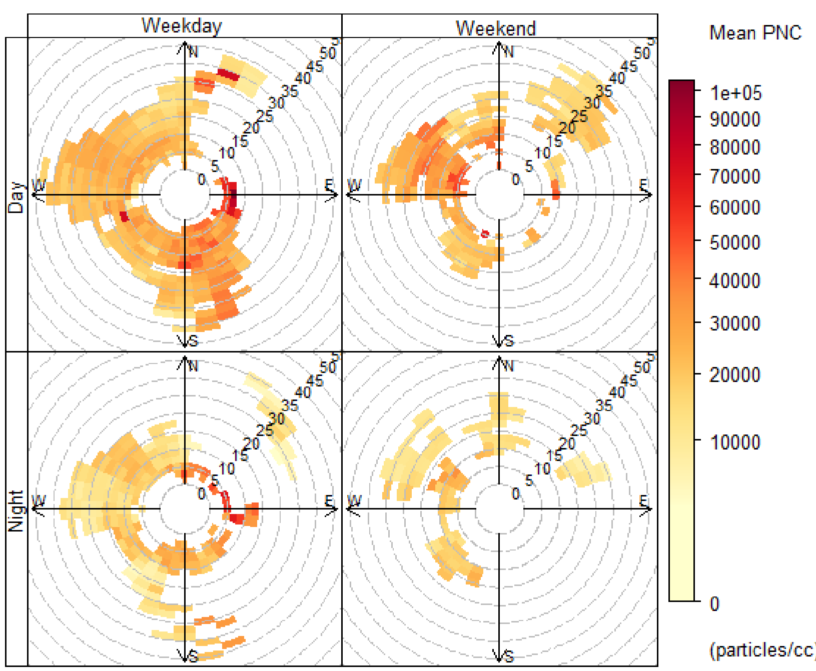

Figure 9: Pollutant rose for PNC. The highest elevated concentrations occurred during weekday days with south to east winds. The highest PNC levels recorded were at low wind speeds from the east.

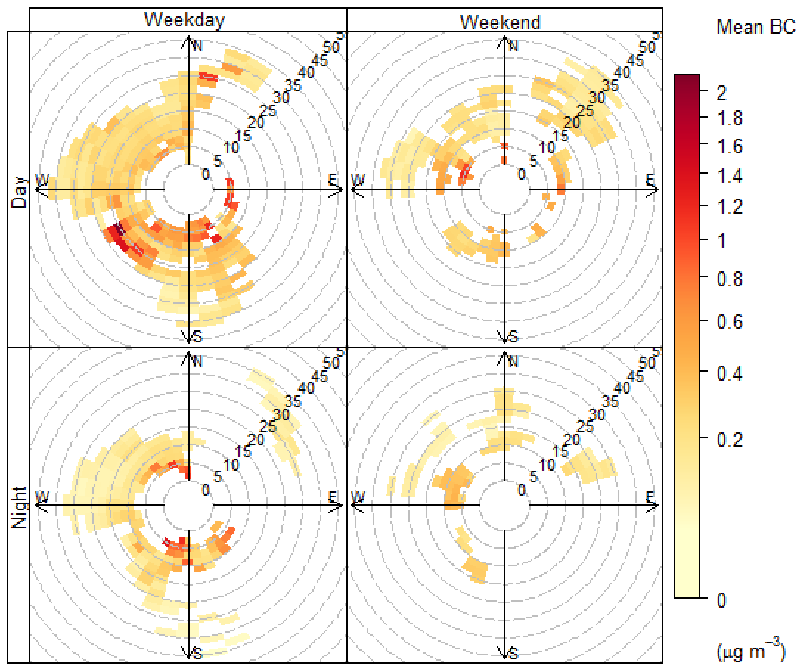

Figure 10: Pollutant rose for BC. The highest elevated concentrations occurred during lower wind speeds and during the weekday days when winds were from the southwest.

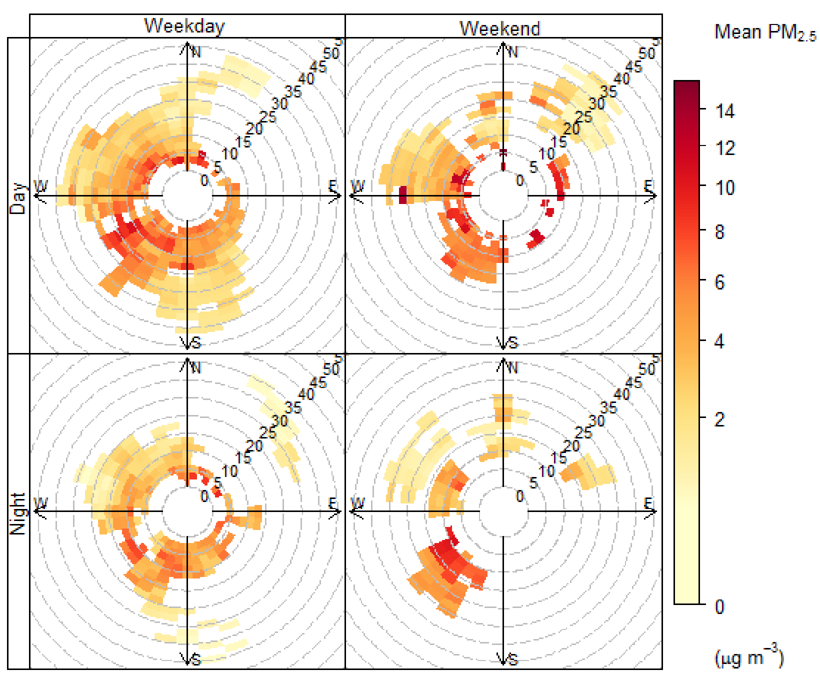

Figure 11: Pollutant rose for $PM_{2.5}$. Elevated concentrations occurred at low to moderate wind speeds from most directions, with consistently higher levels when winds were from the southwest.

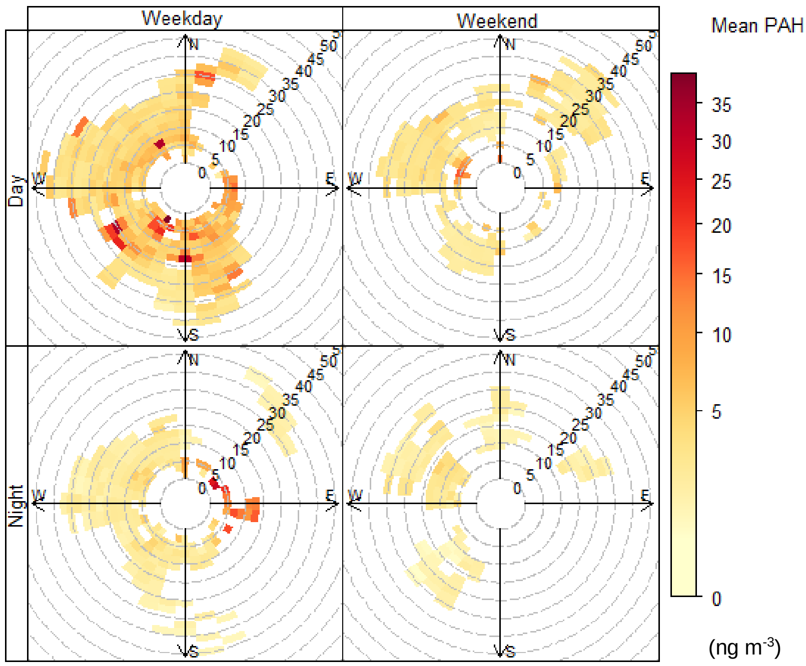

Figure 12: Pollutant rose for PAH. Elevated concentrations were measured during weekday days when winds were from the southwest to southeast. Additionally, weekday nights had higher concentrations during easterly winds.

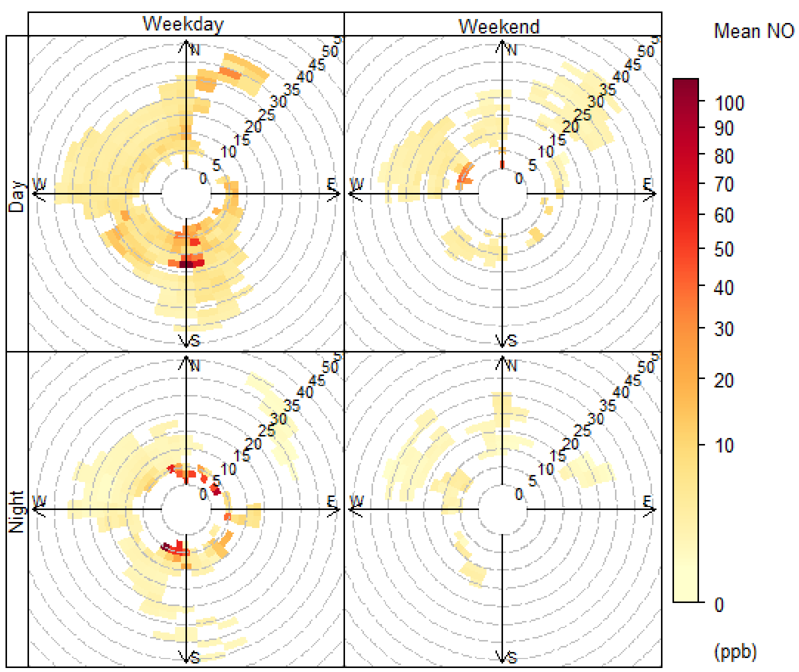

Figure 13: Pollutant rose for NO. Concentrations in general were relatively low, except at low to moderate wind speeds when winds were from the south (both weekday days and nights). Weekday nights also contained elevated NO concentrations at low wind speeds from the north to northwest.

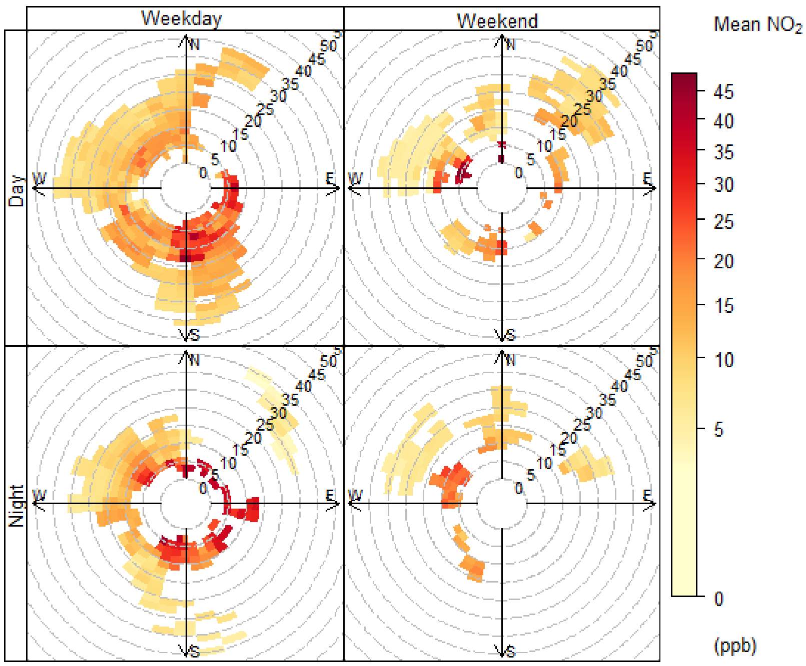

Figure 14: Pollutant rose for NO_2. Elevated concentrations were common at lower wind speeds from most directions, with some of the highest concentrations when winds were from the south to southeast.

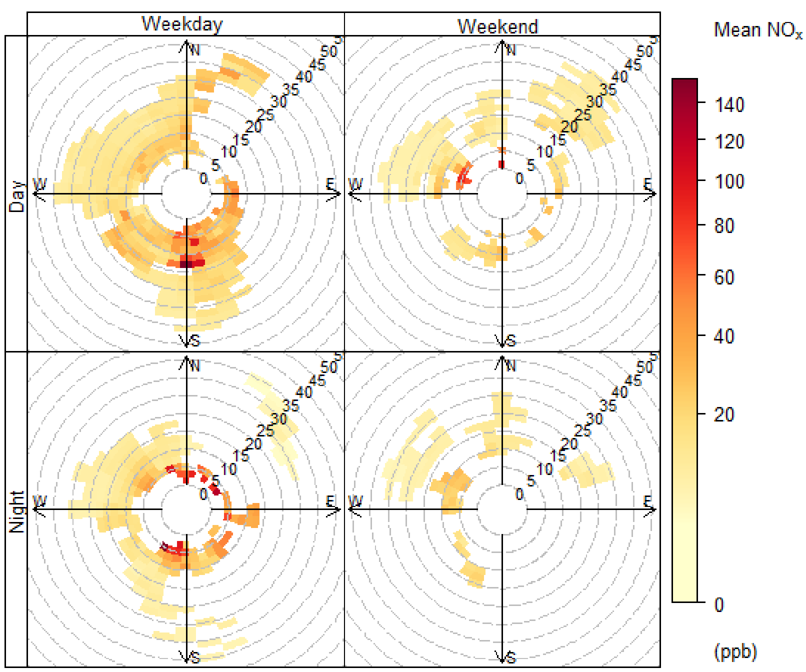

Figure 15: Pollutant rose for NO_X. Low wind speeds resulted in higher measured concentrations, but some of the highest concentrations were found during southerly winds during weekday days at mean speed.

Interpretations

The limited duration of monitoring at ARTfarm introduces some uncertainty over the long-term representativeness of the data. It is possible that higher air pollutant concentrations will be present on some days than the levels observed in the monitoring study. Since this monitoring campaign was completed during winter, typically corresponding to the highest pollutant concentrations, lower concentrations are expected for other seasons. Construction activity at ARTfarm likely influenced measurements when winds were from the northwest to northeast quadrant or at very low wind speeds, but the number of days with construction activity was observed to be low. No construction activity was observed on the weekends or holidays. Construction activity typically consisted of diesel-powered dump trucks entering the site to unload dirt, and a single, large diesel-powered front-end loader working onsite.

Air pollutant concentrations measured at ARTfarm were found to be well below the NAAQS. Given the large margin between observed levels and the NAAQS during a winter (i.e., a worst-case scenario), it is unlikely that NO_2 or $PM_{2.5}$ levels at ARTfarm will at any point approach the NAAQS, although it cannot be completely ruled out. It should be noted that these are the only two pollutants measured during the monitoring campaign that are regulated by the EPA, and their compliance does not necessarily qualify the air as being "healthy." The other pollutants measured (not regulated by the EPA) have shown associations with various negative health effects and should be considered when looking at the overall ambient environment at ARTfarm. Near-roadway research often uses NO_2 not as a single pollutant of concern, but rather as a marker of the large mixture of traffic-related pollutants that are elevated near busy roads and highways. Additionally, $PM_{2.5}$ is usually a regional pollutant and is thought to present health risks below the EPA standard. Measured $PM_{2.5}$ at ARTfarm is very likely to be similar to other measurements of $PM_{2.5}$ within the Boston metropolitan area, whereas PNC (not regulated) is highly dependent on nearby sources, and sources further away during high wind speeds. Focusing on the NAAQS is generally not the best method for assessing locally-sourced air pollution hazards.

For the gases, the highest concentrations are mostly during lower wind speeds, pointing to local sources playing a major role in the NO_X concentrations at ARTfarm. NO was fairly low at wind speeds greater than 5 mph, except during weekday nights. NO_2 was elevated from nearly all wind directions at wind speeds <15 mph, which occurred $>50\%$ of the time. Possible sources are McGrath Highway and the nearby shopping centers, both of which involve relatively high numbers of vehicles. In contrast, the particles tended to be a mix of both local and distant sources, based on some wind directions showing higher concentrations at higher wind speeds. This is indicative of pollutant transport from major sources further away.

For the particles, the pollutant roses showed quite interesting results. There did not seem to be one particular trend across all particle-based pollutants. PAHs, for example, were for the most part elevated during weekday days at varying wind directions. Black carbon on the other hand was elevated during weekday days when winds were from the southwest, which could possibly be due to the commuter rail line which is only 600 ft. away, and in some cases winds from the southeast.

$PM_{2.5}$, being a regional pollutant, had relatively little change in concentration due to wind direction, although southwest winds did correlate to higher $PM_{2.5}$ concentrations.

PNC was highest when winds were from the east, which may in large part be due to the MBTA commuter train, traffic along Interstate 93 (~150,000 vehicles/day), and/or to some extent the MBTA maintenance facility, but was also raised substantially during typical winds (northwest to southwest). Figure 9 shows a band of elevated PNC at lower wind speeds during the week from the direction of the highway. PNC was measured to be between 30,000 – 40,000 particles/cm^3, which is not as high as measured from other wind directions, but elevated well above background levels that might be found >3,000 ft. from major local sources. Weekend days under the same wind conditions show even higher PNC. This could be due to increased traffic around the shopping plaza adjacent to McGrath Highway. The highest PNC levels were found in the south-to-east quadrant during weekday days, and north-to-west quadrant during weekend days. Lower wind speeds generally resulted in elevated PNC regardless of wind direction. South-southeast winds resulted in higher PNC than did other sectors regardless of wind speed, which suggests sources further away are also impacting pollution levels at ARTfarm. This could include the I-93 northbound tunnel exit, downtown Boston, and/or Logan airport. Likely sources for some of the major contributors to air pollution at ARTfarm are shown in Figures 16-17 (local and distant sources, respectively).

Figure 16: Map of likely local contributors (may be others) to air pollution measured at ARTfarm. Both MBTA lines near ARTfarm have a combined ~90 trips/day during the week and ~30 trips/day on weekends.

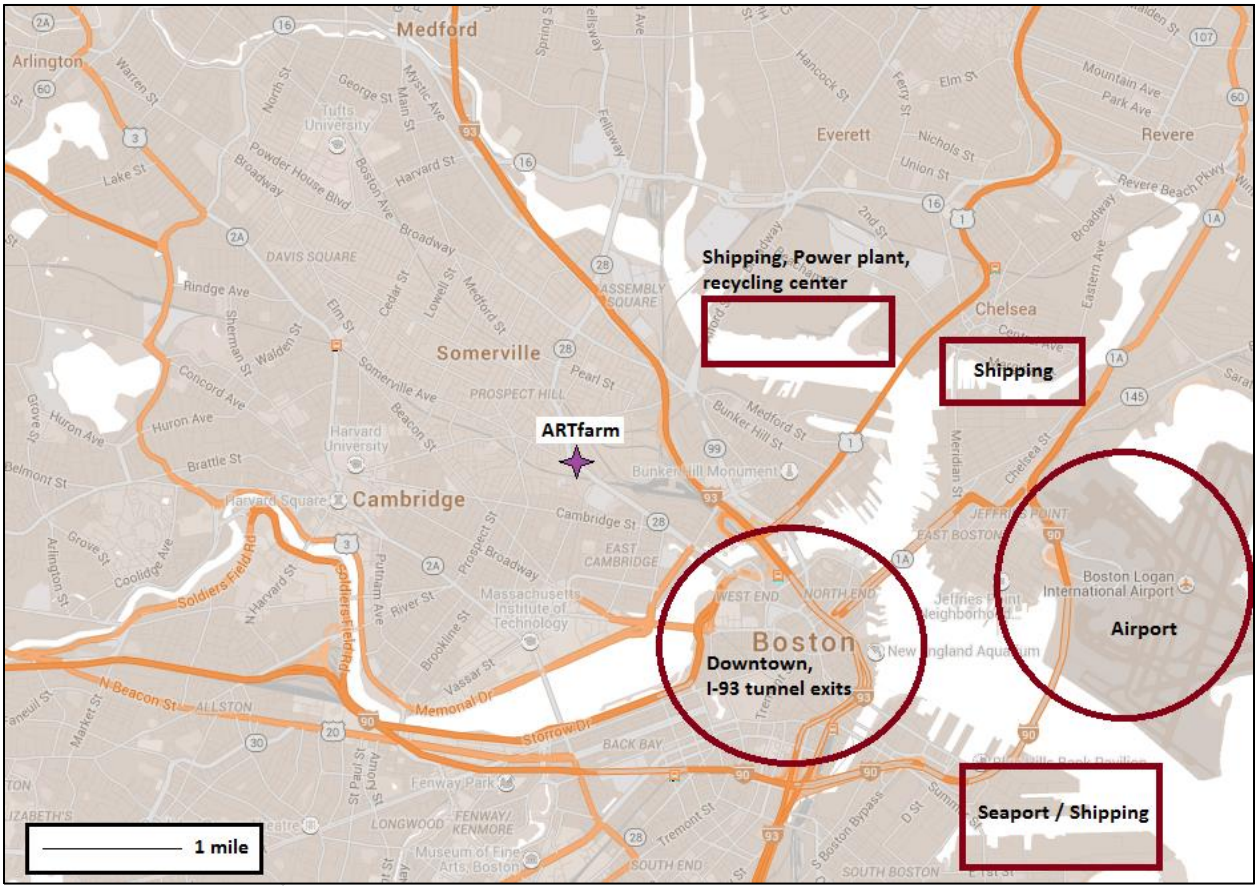

Figure 17: Map of likely distant contributors (may be others) to air pollution measured at ARTfarm.

When reviewing this report, it is important to keep in the mind the percentage of wind coming from directions correlated with the greatest pollutant concentrations measured at ARTfarm. While the southwest-to-southeast quadrant did show elevated concentrations, these directions only occurred 25% of the time. Most of the time winds were from the northwest-to-southwest quadrant.

Recommendations

One of the main reasons for this monitoring campaign was to provide insight into possible exposure levels of visitors to ARTfarm and to gain some insight into how to possibly minimize their exposure. One method of reducing exposure to visitors would be to install high-efficiency particulate arrestance (HEPA) filters in buildings where people are expected to spend a substantial amount of time. This can be accomplished by designing or retrofitting HVAC systems to use HEPA filters on air intake and recirculation ducts. A filter with a minimum efficient reporting value (MERV; a measure of the effectiveness of air filters with a range of 1-20, higher being better) of at least 13 is recommended for the removal of fine and ultrafine particulates with a MERV rating of 16 or greater being preferred. It is important that windows remain closed to ensure the filters are effective in reducing pollutant levels indoors. It should be noted that filters with higher MERV ratings will increase electricity demand. In buildings without HVAC systems (e.g., greenhouses), standalone air filtration units can also reduce pollution levels, assuming windows remain closed. HEPA filters are not designed to remove gases, thus will only be effective against particulates.

Reducing pollutant concentrations outdoors at ARTfarm is much more challenging. Physical barriers, such as solid walls, are sometimes proposed for local pollutants. The barriers will not prevent air pollution from entering the site, but they can reduce concentrations on the leeward side of the barrier. Taller barriers will create larger areas of lower concentration of the leeward side. Buildings can also be positioned to act as barriers. More thought and discussion would be needed before recommending the installation of barriers (and their location) at ARTfarm due to the complexity of the issue. For example, during weekday days ARTfarm saw higher concentrations of black carbon with southwest winds, while PNC was highest during east winds. Vegetative barriers could also be considered, but their effectiveness is likely minimal. They would need to be evergreen, very thick, and with foliage down to ground level.

Air pollution education for ARTfarm visitors could also be considered, especially since it is relatively inexpensive to implement. It may not be feasible to protect the outdoor locations under all conditions, but it may be possible to inform people of the air quality at ARTfarm giving them the opportunity to decide on their own whether they should wait for another day to visit the site. A weather station and inexpensive pollutant sensors could be installed at the site with data uploaded in near-real time online for people to easily access. It is not realistic to monitor all pollutants present in the air, but even just a couple of simple monitors could provide valuable information to the public.

A second monitoring campaign, not necessarily the same length as this one was, could provide useful pollution information during other seasons. This monitoring campaign was completed during winter when it is likely that fewer people are outdoors at ARTfarm, although was a good measure of a worst-case scenario. Monitoring for a period of time over the summer, for example, would provide more realistic exposure estimates for times when more people are expected to be gardening and attending outdoor events at ARTfarm. It would also provide an opportunity to explore the seasonal trends in pollutant concentrations at the site and rough estimates of spring and fall concentrations (assuming monitoring was conducted in summer when pollutant concentrations are typically lowest). Also, the prevailing winds shift slightly as the seasons change and could impact the overall average concentration observed at ARTfarm.

A separate interest of the Somerville Arts Council was to explore the possibility of using ARTfarm as a test bed for pollutant uptake in edible plants. There may be an opportunity to work with researchers at Tufts University on this idea, specifically Dr. Kurt Pennell in the Department of Civil and Environmental Engineering, but would require additional thought and a discussion with Dr. Pennell. Saumel *et al.* (2012) used absorption spectroscopy to look at the uptake of trace metals in inner city vegetable crops and found significant increases in trace metals with increased nearby traffic, similar to the outcome in a more recent paper on urban gardens in Sao Paulo, Brazil (Amato-Lourenco *et al.*, 2016). Antisari *et al.* (2015) found similar results, not only looking at overall accumulation of metals in plants, but both surface deposition and tissue accumulation. They reported soilless planting systems substantially reduced accumulation of metals in plants. Looking at PAHs, Tao *et al.* (2004) had results suggesting uptake by foliage was the primary pathway for PAHs in the atmosphere to vegetables. ARTfarm may be positioned in an ideal location for exploring similar topics. For example, a study exploring the placement of edible plants under different protections (e.g., behind barriers, out in the open, inside greenhouses with HEPA filtered air) and how those different protections impact pollutant uptake into plant matter could be interesting and of value.

Conclusions

Through a 37-day winter monitoring campaign, Tufts researchers were able to provide a baseline understanding of the air quality conditions at the proposed ARTfarm site. Recommendations have been provided to help address some of the air pollution exposure concerns expressed by the Somerville Arts Council.

References

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Sincerely,

Matthew C. Simon

Matthew C. Simon
PhD Candidate
Tufts University

cc: A. Bob, City of Somerville
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D. Brugge, Tufts University