Particulate matter pollution around the Fore River Basin: Comparing local estimates to regional observations and dispersion modeling estimates

Technical report

Fore River Residents Against the Compressor Station,
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Abbreviations
EPA: Environmental Protection Agency, **$PM_{2.5}$**: Fine particulate matter (< 2.5 microns), **NAAQS**: National Ambient Air Quality Standards, **FEM**: Federal Equivalent Method, **FRM**: Federal Reference Method, **DEP**: Department of Environmental Protection, **ANOVA**: Analysis of variance

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Summary

The Fore River Basin (bordering Braintree, Quincy, and Weymouth, MA) currently hosts multiple industrial sources of air and water pollution. Nonetheless, the area may suffer increased air and noise pollution from additional industrial expansion (namely, a large gas-fired compressor station). The compressor station proposal used air pollution models that predict the compressor station will cause significant elevations in toxic air pollution, but will not cause local air quality to violate EPA standards. We measured one toxic pollutant (fine particulate matter) at multiple sites around the Fore River and found significant differences between peak particulate matter concentrations measured at a regional monitor compared to our local estimates. The data imply that the existing health burden due to fine particulate matter pollution in communities surrounding the Fore River Basin, including environmental justice communities of concern and sensitive populations, has been underestimated. Given the air quality discrepancies found during a relatively short monitoring period, additional industrial expansion in the Fore River Basin may be more likely to jeoperadize health and violate EPA air quality standards than previously realized. Furthermore, the results question the extent to which the current regulatory review process accurately evaluates toxic air pollution exposure risks.

Background

Particulate matter (both coarse and fine) accounts for two of the six EPA criteria air pollutants. Elevated concentrations of fine particulate matter ($PM_{2.5}$) are associated with adverse health outcomes such as cardiopulmonary disease and all-cause mortality [1-5]. However, the widespread effects of particulate matter on non-respiratory health outcomes such as low birth weight [6], autism [7], and dementia [8] are becoming increasingly apparent.

Because of its effects on human health, significant sources of $PM_{2.5}$ emissions must demonstrate compliance with multiple regulations such as the National Ambient Air Quality Standard (NAAQS) prior to approval. Compliance is often demonstrated by combining the background $PM_{2.5}$ concentration, existing local sources of $PM_{2.5}$, and new source emissions using dispersion modeling. Background $PM_{2.5}$ concentrations are typically obtained from stationary regional air quality monitors in a comparable urban or rural setting. State agencies provide significant local sources of $PM_{2.5}$ emissions along with their emissions rates.

Demonstrating compliance with air quality standards using dispersion modeling is predicated upon several questionable assumptions. First, regional monitors can be located over twenty miles from the community of interest and may not accurately reflect local concentrations – and hence local toxic exposures. Second, the company filing the application hires their own consultants to conduct the emissions analyses and air dispersion modeling. This raises the possibility of bias in preparing the regulatory application. Third, dispersion modeling may not accurately represent local conditions (coastal and thermal inversions, more complex terrain effects, temporal variation in emissions rates, etc). Fourth, dispersion modeling often omits other potentially important sources of particulate pollution, such as traffic-related (mobile) air pollution sources and construction.

To address these potential limitations in the regulatory review process, we sought to obtain estimates of local $PM_{2.5}$ concentration through direct measurement. We chose to collect data around the Fore River Basin of coastal Massachusetts, home to multiple sources of toxic air and water pollution. Local resident concerns include a history of toxic industrial exposures, suspected disease clusters (including respiratory disease, neurologic disease, and cancer), and the existing high level of industrial activity in the Fore River Basin. In addition, some communities immediately adjacent to the Fore River qualify as environmental justice communities and therefore require special consideration in regards to existing and future pollution burdens as well as their inclusion in any decision-making processes.

Despite these concerns, the Fore River Basin is undergoing review as a potential site to host a natural gas pipeline compressor station [9]. Most compressor stations use powerful turbines to burn natural gas and generate the compression necessary for operating large interstate transmission pipelines under high pressure. As with burning any fossil fuel, methane combustion at compressor stations produces multiple air pollutants including carbon monoxide, carbon dioxide, nitrogen dioxide, formaldehyde, and fine particulate matter.

The regulatory application for the proposed compressor station also used dispersion modeling to combine regional air quality data, in this case from a purportedly comparable urban setting ~8.5 miles away, with local industrial emissions data. While clearly adding to the substantial existing toxic air pollution burden, the modeling and compliance analysis demonstrated that the station's emissions would not violate EPA standards such as the NAAQS.

Given the previously listed concerns, we sought to address the following questions: Does local air quality in the Fore River Basin differ from air quality at comparable monitoring sites? How closely do regional data and dispersion modeling reflect local conditions? And, how might future projects like a gas-fired compressor station affect air quality when local measurements are incorporated?

Methods

Data collection and processing

Particulate matter estimates were obtained using a Dylos DC1100 Pro monitor with PC interface (Dylos Corporation, Riverside CA). The Dylos monitor measures two sizes of particle counts via proprietary laser technology. It is calibrated by the company to measure particle sizes greater than 0.5 µm and greater than 2.5 µm ("small" and "large" particles, respectively). The fine particle count corresponding to $PM_{2.5}$ can be obtained by calculating the difference between the two channels. State and federal agencies have compared Dylos units in field studies to EPA-approved $PM_{2.5}$ monitors and found sufficient correspondance between them (r^2 of 0.533 [10], 0.58 [11] , and 0.81 - 0.83 [12] to justify their use in the present study. Data were collected at three separate locations surrounding the Fore River Basin, varying in distance between approximately 1.23 and 2.66 kilometers, located at approximately 45, 150, and 320 degrees relative to the Fore River Basin. The unit was protected from precipitation, direct wind, and direct sunlight by a variation of the EPA's "bowl on a pole" apparatus used in their field testing [10]. Data were collected between Dec 5, 2015 and Feb 25, 2016. 24 hour average large and small particle counts were obtained from the Dylos monitor according to the manufacturer's directions. Statistical analyses were performed using OpenStat software [13]. The full monitoring period included 67 complete 24 hour measurements.

Only one field study produced a model describing the relationship between Dylos 24 hour particle count averages and 24 hour $PM_{2.5}$ mass concentration, as determined by a co-located Federal Equivalent Method (FEM) monitor [10]. The linear regression model from that study was used to convert particle counts to estimates of $PM_{2.5}$ concentration [10]. This approach resulted in eleven days with negative particle counts (an impossible proposition). The lowest small particle count was therefore used as the next best estimate for the y intercept of the regression equation.

Comparison to cofounding weather variables

The nearest 24 hour average temperature, relative humidity, wind speed, and wind direction were obtained from weather stations reporting to an online service [14]. The nearest weather station was used (either KMAWEYMO9 or KMABRAIN4). Wind direction as measured at the nearest weather station was converted through multiple steps. First, the location in degrees was determined between each monitoring site and a point midway between the two highest $PM_{2.5}$ sources in the Fore River Basin (Braintree Electric Light Department and Constellation Energy generating units). The difference in degrees between the monitor location and wind direction for each 24 hour period was calculated and used for subsequent analysis. Pearson correlations were determined between 24 hour particulate matter estimates and each weather variable.

Comparison to Harrison Ave monitor (Roxbury, MA)

A recent regulatory filing including a methane gas compressor station in the Fore River Basin used background values obtained from a FEM beta attenuation $PM_{2.5}$ monitor in Roxbury, MA, about 8.5 miles away from the site of interest [9]. Recent particulate matter data were obtained from the Massachusetts DEP air quality website (http://www.mass.gov/eea/agencies/massdep/air/quality/), encompassing the monitoring period. Data from the DEP listed data collection times as midnight to midnight, whereas the measured data were for 24 hour periods starting between approximately 10:00 am to 2:00 pm. To determine whether differences in 24 hour monitoring period might affect the data, PM estimates were correlated with the same day data from DEP, the day prior, and the day after.

Health effects analysis

All fully resolved peaks exceeding 15 µg/m^3 (either dataset) were chosen for additional analysis. The maximum concentration for a given peak was manually identified in the Harrison Ave and Fore River datasets with the matching maximum concentration from the other dataset. Each value was classified as a "good" ($PM_{2.5}$ concentration <15 µg/m^3) or "moderate" ($PM_{2.5}$ concentration 15 – 40 µg/m^3) air quality day, according to the EPA's Air Quality Index. $PM_{2.5}$ concentrations were compared to results from a study evaluating the relationship between 24 hour $PM_{2.5}$ concentrations and stroke over a range of concentrations comparable to the current data set, in the same greater metropolitan area (Boston) [4].

Comparison to NAAQS standard and epidemiology research
The arithmetic mean was calculated for the Harrison Ave monitor data and the Fore River estimates. The first value from each dataset exceeding the 98th percentile was used for comparison to the 24 hour $PM_{2.5}$ NAAQS standard.

Results

Relationship to meteorologic variables and location
Mean 24 hour $PM_{2.5}$ estimates were compared to several meteorologic variables (Figure 1). There was no correlation between $PM_{2.5}$ estimates and temperature ($r = 0.168$, $p = 0.174$), relative humidity ($r = 0.1457$, $p = 0.239$), and wind direction ($r = -0.040$, $p = 0.75$). There was a significant correlation between $PM_{2.5}$ estimates and wind speed, where lower wind speeds were associated with higher estimates ($r = -0.408$, $p = 0.001$). There was a significant effect of monitoring site by one-way ANOVA ($F = 3.28$, $p = 0.04$), but differences between individual site means were not significant (Bonferroni post-hoc test).

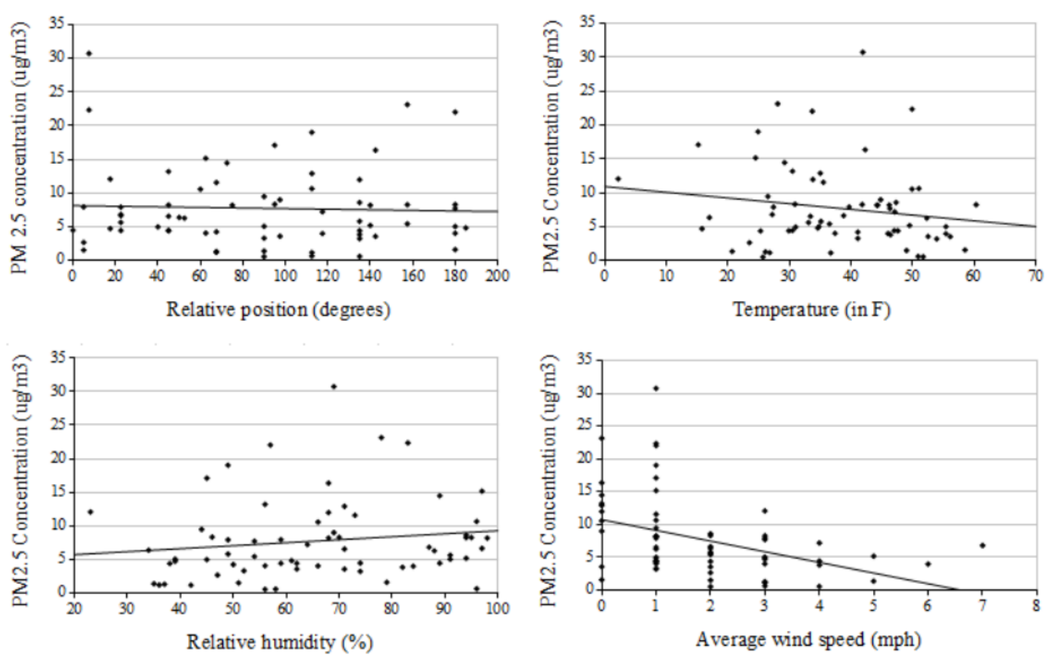

Figure 1: Relationship between Fore River basin $PM_{2.5}$ estimates, location, and meteorologic variables. Only the correlation between $PM_{2.5}$ concentration and wind speed was statistically significant.

Relationship to regional monitor data

Since our 24 hour period began mid-day to early afternoon, compared to the Harrison Ave data collection period that began at midnight, we compared our 24 hour averages with the same day, previous day, and next day 24 hour averages from the Harrison Ave monitor. The correlation was not significant for the preceding day's values but was for the same day and subsequent day (both $p < 0.001$) although the same day correlation was not as strong as the next day (0.426 vs 0.576 respectively). Fore River estimates and subsequent day values were plotted for the entire measurement period (Figure 2). Mean 24 hour $PM_{2.5}$ concentration from the Harrison Ave monitor (8.28 μg/m^3) was similar to estimates from the Fore River (7.72 μg/m^3) and not significantly different (paired samples $t =$ -0.92, $p = 0.361$). However, the overall distribution of values between Harrison Ave and the Fore River Basin was significantly different (Kolmogorov-Smirnov $D = 0.254$, $p < 0.001$). This is likely due to at least in part to the higher peak 24 hour $PM_{2.5}$ estimates in the Fore River Basin (Figure 2).

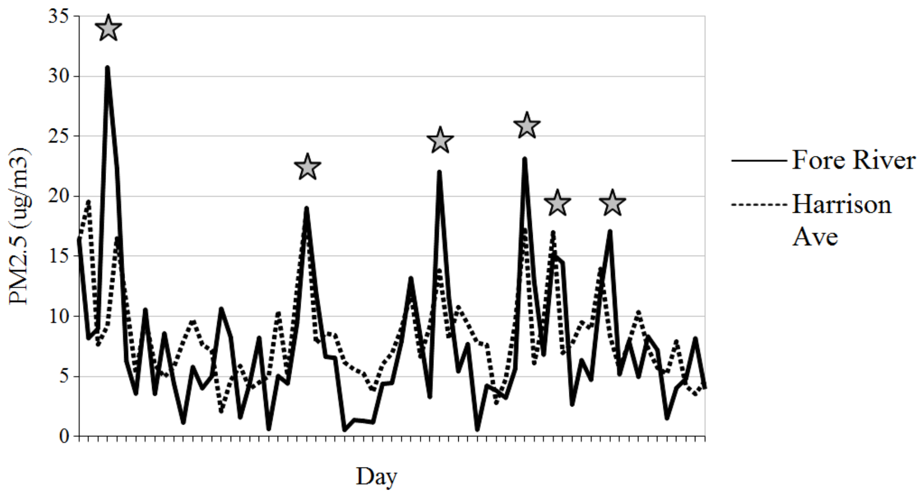

Figure 2: Comparison of 24 hour $PM_{2.5}$ concentrations from a stationary urban monitor (dashed line) and estimates from the Fore River basin (solid line) over the entire monitoring period. Starred peaks were chosen for further comparison.

Health effects analysis

To begin understanding the health implications of our results, we compared our data to results from a study conducted in the Boston metropolitan area that found an association between elevated stroke risk and elevated $PM_{2.5}$ pollution [4]. Days with air quality classified as "moderate" for $PM_{2.5}$ pollution, according to the EPA's Air Quality Index (> 15 μg/m^3), were associated with a 34% increase in the odds (similar to risk) of a stroke in the

Harrison Ave	Air quality	Increased stroke risk?	Fore River	Air quality	Increased stroke risk?
16.5	Moderate	Yes	30.7	Moderate	Yes
18.8	Moderate	Yes	19	Moderate	Yes
13.8	Good	No	22	Moderate	Yes
17.4	Moderate	Yes	23.1	Moderate	Yes
17	Moderate	Yes	15.2	Moderate	Yes
13.9	Good	No	17.1	Moderate	Yes

Table 1: Corresponding peak 24 hour $PM_{2.5}$ values from a regional background monitor and local estimates, along with determination of air quality and stroke risk (after Wellenius et al [4]). All peaks fully resolved in the monitoring period that exceeded 15 μg/m^3 were included. Units in μg/m^3.

following day relative to days with "good" air quality (< 15 μg/m^3). We therefore identified the peak $PM_{2.5}$ concentration for any days with "moderate" air quality in either location (Table 1). We then categorized the air quality at both sites, and subsequently the stroke risk. Both sites measured $PM_{2.5}$ concentrations that, based on published data [4], increased stroke risk. However, there were more days with moderate air quality and consequently increased stroke risk in the Fore River Basin (6 of 6 peaks) relative to urban Boston (4 of 6 peaks).

Comparison to compressor station regulatory analysis

The gas compressor station dispersion modeling and regulatory compliance analyses showed that additional $PM_{2.5}$ emissions from the station would exceed the EPA's Significant Impact Level [9]. The maximal predicted effect on local $PM_{2.5}$ concentrations would be an increase of up to 3.2 μg/m^3 attributable to the station's emissions. Background $PM_{2.5}$ values, obtained from the Harrison Ave monitor, were combined with anticipated emissions from the station and four existing industrial sources of $PM_{2.5}$ pollution in the Fore River Basin (as determined by the MA DEP). The combined background, local source, and proposed emissions in this analysis did not violate the annual or 24 hour NAAQS for $PM_{2.5}$ (20.95 μg/m^3, less than the 24 hour $PM_{2.5}$ standard of 35 μg/m^3) [4].

Since we obtained data from the immediate vicinity of the proposed compressor station, our estimates represent the background plus local sources. As a worst case scenario, we combined the 98th percentile (as calculated for the 24 hour $PM_{2.5}$ NAAQS) value from our data with the maximal projected $PM_{2.5}$ emissions from the compressor station (3.2 μg/m^3). The resulting value of 26.3 μg/m^3 also does not violate the NAAQS. However, that value exceeds the corresponding Harrison Ave value of 16.4 μg/m^3 by nearly 10 μg/m^3. That is, peak $PM_{2.5}$ concentrations in the Fore River Basin (including in multiple environmental justice communities of concern) could be at least 60% higher than nearby urban communities in Boston. If additional peaks over 30 μg/m^3 were found over a more extensive monitoring period, and our current maximum value of 30.7 μg/m^3 were used as the 98th percentile equivalent, then the worst case $PM_{2.5}$ concentration of 33.9 μg/m^3 would nearly exceed the NAAQS.

Discussion and Conclusions

We sought to obtain independent, local data that would better characterize air quality in an existing industrial area. Air quality in the Fore River Basin is important both under current emissions levels as well as after further increases in local air pollution – if a gas-fired compressor station is approved for construction and built there. Our method produced feasible estimates of $PM_{2.5}$ concentration both in terms of expected range as well as the detection of peak elevations that closely correlated with those detected by the nearest urban FEM monitor. Mean concentration did not vary significantly over the monitoring period, but the overall distribution of $PM_{2.5}$ concentration was significantly different –

likely due at least in part to higher peak concentrations in the Fore River Basin. Since 1 hour and 24 hour increases in $PM_{2.5}$ have been associated with adverse cardiopulmonary outcomes (asthma, stroke, heart attack, and others [1-5]), the relatively higher peak concentrations likely have an adverse effect on health outcomes in the Fore River Basin. Overall, the data suggest that the pollution burden due to $PM_{2.5}$ is higher in the Fore River Basin relative to comparable urban areas, and that regulatory analyses for industrial projects in the Basin (e.g., a gas fired compressor station) must be reconsidered.

Meterologic and spatial covariates

Our data were collected with a device that has undergone satisfactory evaluation in outdoor field trials conducted by different state and federal agencies. Three observations support the validity of our method for producing meaningful $PM_{2.5}$ estimates. First, our estimates were significantly correlated with those obtained from the nearest comparable monitor. We would expect a close relationship between the two sites located 8.5 miles apart, but not necessarily identical values given the considerable differences in nearby stationary and mobile pollution sources, local terrain, etc between the two monitoring locations. Second, our method replicated known effects of atmospheric turbulence (in our data, average wind speed) on pollutant concentration: less turbulent days were associated with higher $PM_{2.5}$ concentrations, but variations in relative humidity or temperature were not. Third, there was a nearly identical temporal alignment between peak $PM_{2.5}$ concentrations detected at the FEM monitor and those detected by our method.

Does local air quality in the Fore River Basin differ from air quality at comparable monitoring sites?

There was no statistically significant difference in mean $PM_{2.5}$ between the Fore River Basin and Roxbury (Boston) over the present monitoring period. However, the overall distributions were significantly different, likely due at least in part to elevated peak concentrations on “moderate” air quality days in the Fore River Basin. Given the considerable difference in stationary and mobile $PM_{2.5}$ emissions sources between the two sites, along with local climate differences, this is not entirely unexpected. In fact, these data provide empiric evidence that using dispersion modeling to combine background and local emissions data may not provide accurate estimates of local air quality despite the widespread use of this strategy in permit applications for major and minor sources of air pollution.

How closely do regional data and dispersion modeling reflect local conditions? How might future projects like a gas-fired compressor station affect air quality when local measurements are incorporated?

There is an important discrepancy between recent dispersion modeling results and our direct observations. Dispersion modeling for the Weymouth compressor station used three $PM_{2.5}$ values: background data from the Harrison Ave monitor, four sources of local $PM_{2.5}$ emissions, and additional emissions from the proposed compressor station. Our estimates would correspond to the background plus existing local source estimates. The compressor station regulatory filing did not report the combined background and local source values that would enable a direct comparison. However, it is clear that our estimates do not reflect those produced by the applicant's consultants: Our observations exceed the modeled estimates that even include the projected compressor station emissions (26.3 and 30.7 $\mu g/m^3$ vs 20.95 $\mu g/m^3$ respectively), despite the fact that the station has not yet been built.

If one considers the worst case scenario based upon the present data set, additional emissions from a natural gas compressor station could result in peak $PM_{2.5}$ concentrations that nearly cross the 24 hour NAAQS standard (33.9 $\mu g/m^3$ vs 35 $\mu g/m^3$). Our measurements were obtained over a relatively short time period over a single season at a limited number of sites, and may not have captured the full range of variation in $PM_{2.5}$ over a year. Furthermore, the proposed compressor station has not yet obtained full regulatory approval but has already been listed for expansion under a separate regulatory application [15]. More extensive local monitoring, especially if the natural gas compressor station is built and potentially expanded in size, may reveal violations in the 24 hour NAAQS standard for $PM_{2.5}$ in the Fore River Basin.

Differences between dispersion modeling predictions and our data potentially reflect multiple sources of error in the modeling process. First, there may be error introduced by using historical weather data and emission rates from local sources. Second, residents highlighted additional sources of $PM_{2.5}$ pollution in the area that are real sources of emissions but were not accounted for in the modeling: a fertilizer factory, motor vehicle traffic on major transportation routes, diesel train emissions, and diesel shipping boat emissions. Third, residents noted that previous environmental studies in the area demonstrated the impact of coastal inversion events on local air quality. Coastal inversion events may not have been adequately incorporated into dispersion modeling but could have affected local air quality during our monitoring period.

This study and report focused exclusively on one criteria pollutant emitted by fossil fuel consumption, $PM_{2.5}$. Other pollutants including nitrogen dioxide, ozone, and hazardous air pollutants emitted by compressor stations such as formaldehyde, benzene, and toluene are also important and should be reconsidered for more extensive analysis as well. In addition, residents have expressed concerns about pollutant adsorption or deposition into wetlands, lakes, rivers, and soil which have not yet been adequately addressed by the review process.

Potential health effects

Particulate matter is regulated as a criteria pollutant precisely because it is toxic and harmful for human health. There is an extensive scientific literature demonstrating the effects of $PM_{2.5}$ on health outcomes. What is becoming increasingly clear is that $PM_{2.5}$ affects a surprisingly diverse variety of health outcomes, and continues to impact human health even at concentrations that do not violate the NAAQS that are promulgated to protect human health. There are challenges in extrapolating health outcomes from previously published studies to the current data. But compared to a recent epidemiologic study conducted in the same metropolitan region, with the same climate and comparable ranges of $PM_{2.5}$ concentrations [4], it seems likely that the elevated $PM_{2.5}$ concentrations we identified would have had real effects on health outcomes (for example, see Table 1). Those health outcomes affect the community members who are our neighbors, friends, and family.

There is also an increased incidence of lung cancer among women in Weymouth [16]. Women with cancer, other cancer patients, those with chronic cardiopulmonary disease, young children, and the elderly all comprise sensitive populations of concern, along with the environmental justice communities nearby.

Conclusions

Using previously validated technology, we obtained estimates of $PM_{2.5}$ concentrations in the Fore River Basin that differed from a comparable regional monitor (both statistically and in terms of potential health outcomes). Additional industrial expansion (e.g., a natural gas compressor station) would only further endanger the health of local residents. Without local observations such as those presented here, the true community burden of air, water, and soil pollution may be underestimated during the regulatory approval process. These data also challenge the validity of using dispersion modeling to estimate local pollutant concentrations. The validity of minor and major air quality permit applications, which often rely upon this analytic approach, must therefore also be questioned.

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