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Effects of Topography on Near-Roadway Particulate Matter Concentrations and Diesel Emissions

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Thesis Submitted

To the Benjamin M. Statler College of Engineering and Mineral Resources

At West Virginia University

In partial fulfillment of the requirements for the degree of

Master of Science in Industrial Hygiene

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**Morgantown, West Virginia
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Public Health**

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ABSTRACT

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Andrew Epperly

The purpose of this study is to examine the effects of topography on the concentrations of particulate matter near heavily trafficked roadways. Particulate matter is an attractive tracer for diesel emissions and these emissions have been linked to a variety of negative health effects. Much research has been conducted to characterize particulate matter emissions near roadways, however this work has been conducted on relatively flat terrain. This study was conducted within a valley in the Appalachian Mountains to see if the alternate terrain influenced the size of the particulate matter plume near a roadway.

Particulate matter concentrations were collected and compared to results from literature. Comparisons suggest that there is indeed a connection between the mountainous terrain of the sample location and concentrations significantly different from previous comparable studies. Specifically, the concentration of particulate matter fell to background levels much slower than what was expected and the well-known association between weather inversions and increased particulate matter concentrations was not observed. It is recommended that further study be directed at this question to verify the connection between varied topography and unexpected particulate matter plume characterizations.

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Introduction

The purpose of this study was to investigate the effects of topography on concentrations of particulate matter emitted from diesel emissions near large roadways. Our existing knowledge of when and how these emissions might impact health might be biased by the lack of certain topographical and meteorological conditions in previous studies. This study hypothesizes that the presence of atmospheric temperature inversions and rougher terrain, specifically valleys, will significantly increase the concentration of Ultrafine Particles (UFP) near an interstate and seeks to support this hypothesis. It is believed that inversions in the valley will help contain the UFP that is emitted from diesel engines and cause it to pool in the valley without the intervention of other sources. This would lead to increased concentrations over a wider area than previously suggested and an increased plume length for emitted particulate matter. Importantly, if supported, findings would also suggest that a wider range of distances than those previously thought to be safe from UFP exposure are actually at risk.

In this study, particulate matter concentrations were measured within an area with topography distinct from previous studies, analyzing the collected data for any notable trends, comparing these trends with previously published literature, and confirming or refuting the hypothesis that topography of the sampling area will have an effect on the particulate matter concentrations found there. To meet the study objectives, a sample area was selected where a valley runs perpendicular to a 4-lane interstate highway for approximately a kilometer. Forty samples were collected at varying distances removed from the source between June 2014 and February 2018. This process is outlined within the Methodology section of this report. Results from the analyzed samples showing sustained or increasing concentrations of UFP at distances of nearly a kilometer were then compared to existing literature that proposes limiting the putative area of exposure to 300 meters and are outlined in the Results and Discussion section. Finally, the implications and limitations of the findings of this report on both exposure assessment and regulatory control are discussed within the Results and Discussion section.

Literature Review

Health Effects of Particulate Matter

Epidemiological studies have characterized an association noting detrimental health effects related to elevated vehicle emission exposure. In general, these studies have consistently established significant positive associations between increased vehicle emissions and adverse health effects across a wide variety of ailments including increased risk of reduced lung function [4,17,22,31], cancer [20,27,30], asthma [24,25], adverse respiratory symptoms [9,16,33,34], heart attack [2], adverse birth outcomes [1], and even mortality [13]. These consistent findings highlight the significance of examining the atmospheric concentrations of particulate matter near inhabited areas.

Vehicular emissions are composed of a variety of different chemical species, so it is difficult to determine which agent specifically is responsible for a given health effect. For this reason, most of the studies focus on the health effects of particulate matter, which is the most commonly sampled agent. This is due to its relatively low background level compared to other agents, the relative ease at which it is sampled, and a high dynamic range of concentrations at which it is found. These factors combine to make UFP an attractive tracer for other emissions agents [5].

Areas with higher concentrations of UFP are more likely to have populations exhibiting increased incidence of the previously listed ailments. Increased incidence of adverse health effects in effected communities is the driving force behind research into particulate matter emissions. A study conducted by Brugge et al. in 2007 estimates that roughly 10% of all homes in the United States are within 100m of a 4-lane highway [3]. A similar study conducted by Polidori et al. in 2009 found that as much as 50% of the population of highly urbanized areas lives within 1.5km of a freeway [29]. It is important to determine the distance that UFP can propagate away from an interstate to determine exposure levels of individuals living in at risk locations, primarily metropolitan areas and homes near highways.

Vehicle Emissions and Particulate Matter

Diesel emissions are known to be a significant source of particulate matter. A study by the Surface Transportation Policy Project (STPP) showed that vehicular traffic is responsible for up to 10% of particulate matter emissions [32]. This study also showed that in metropolitan areas this percentage is significantly higher, to the point that vehicular emissions are the primary source for UFP emissions. This assertion is supported by other studies that demonstrate that roughly 80%-90% of UFP emissions in urban areas are the result of vehicular traffic [21,28]. The STPP report also states that diesel vehicles are the primary source of vehicular emissions noting a strong association between heavy truck traffic, e.g. diesel vehicles, and the level of particulate matter measured near the corresponding roadway [26]. This assertion is supported by numerous other publications [8,10,11,16,23]. Combined, these statements imply that most of the particulate matter emitted into the atmosphere near roadways comes from diesel vehicle emissions.

The adverse health effects associated with UFP and the dominance of vehicular traffic as a source of UFP have led to a variety of studies attempting to record the characteristics of vehicular emission plumes near roadways. Many these studies have taken place in California [6,7,14,15,36]. This is due to the relatively high density of vehicular traffic and the fact that Los Angeles has some of the most severe air quality problems in America [36]. Other study locations have been similarly sampled in or near large urban centers or heavily trafficked roads [12,19].

All existing studies examining the effects of vehicular traffic on particulate matter emissions were performed on relatively flat terrain. Study areas within cities are generally flat due to construction constraints. However, urban areas contain many buildings which lead to complications in mixing patterns [21]. Study areas near major urban centers tend to have relatively flat terrain as well. No studies were found that examine the effects of severe terrain on the plume or particulate matter generated by road traffic. The relationship between severe terrain and particulate matter emissions from highways should be investigated more in depth. Valleys or other similar terrain could affect the mixing of the particulate matter plume and lead to higher or lower concentrations than would otherwise be expected of comparable areas with flatter terrain. This could be particularly significant in mountainous regions throughout the United States and the world. Within West Virginia it may also contribute to unidentified disparities in expected exposure

risk and actual exposure risk, particularly for those living in southern West Virginia where highly trafficked highways carrying coal or natural gas typically follow valleys through small communities.

Factors Effecting Particulate Matter Plumes

Two meta-studies concluded that the plume resulting from UFP emissions extends to roughly 300m [18,35]. This assertion is generally accepted for unstable meteorological conditions. The studies considered in these meta-analyses were conducted during the day when thermal mixing is significant. Later studies showed that pre-sunrise or stable meteorological conditions can lead to a significantly increased plume length of vehicle emissions potentially in excess of 2 kilometers [6,14]. Pre-sunrise conditions generally lead to lower thermal mixing and lower wind speeds which result in longer plume length [14]. A meta-study of the dynamics and dispersion modeling of UFP and other nanoparticles has shown that dilution is the primary source of dispersion [21]. Therefore, wind speed and time of day are of importance to studies of this type. Increased wind speed increases the turbulence of the air and increases dilution as a result. Pre-sunrise conditions reduce the amount of thermal mixing present in the air while wind speed directly affects the mixing of the air. Both effects can reduce the dilution of pollutants.

Sampling Methodology Differences

There does not appear to be any consistent sampling methodology among studies examining the particulate matter exposure and health risk. Studies generally either sampled at fixed distances from the centerline of the highway or sampled continuously as the sampling platform moved away from the highway. Both sampling methods introduce some form of temporal error to calculations. Mobile sampling platforms must account for the fact that instruments can potentially have different response times. This was typically not a problem for particulate matter sampling since instruments have a low response time. Some studies sampled other chemical species where this concern was

much more pronounced [6]. For particulate matter sampling this can largely be ignored. Stationary sampling must account for the fact that the plume of particulate matter has a travel time and can vary from minute to minute as traffic passes. The effects of this are small and can be controlled by normalizing the data. Studies of this type must also be aware of any high-emission vehicles passing near the sampler and control the resultant spikes in particulate matter readings [36]. Results for studies of both forms produced comparable results.

Normalization was performed for a substantial portion of the studies reviewed and this was often done via different methods. Studies tend to normalize the data that was collected by either using the peak concentration near the highway or by using a form of background concentration. A meta-analysis performed by Karner et al. found that normalizing sample data via a background measurement could result in significant errors in analysis. A background could be taken too close to the highway resulting in a shorter plume length or the background could be taken in an area that is not representative of the actual concentrations near the highway leading to a longer plume. This is not done intentionally, but results from differences in the definition of a background sample. Some studies defined this as the concentration roughly 50m upwind of the highway while some defined it as a sample 500m or 100m from the highway on the downwind side; one study even defined the background as a sample taken on an island that was separate from the island where the rest of the sampling was taking place. This high variance rendered the different studies difficult to compare directly. Karner et al. found that normalizing the data based on a roadside concentration led to much more consistent and comparable plume lengths [18].

It is important to note that the number of samples that were collected within this study is significantly larger than most comparable studies. 40 different sampling dates were included within this study while similar studies typically include 5-20 [6,7,14,15,36].

Summary

Particulate matter concentration has been positively correlated with a wide range of adverse health effects including cancer, respiratory problems, and heart attack. These health effects have led to a range of studies concerned with the extent of particulate matter exposure near highways

with high levels of diesel truck traffic. Studies have examined the effects of wind speed, traffic volume, and time of day however, studies of this nature have thus far been performed primarily within or near metropolitan areas with relatively flat terrain. The purpose of this study is to examine the effects of terrain on particulate matter plume characteristics and partially fill this knowledge gap. This study was conducted within a valley in the Appalachian Mountains where the dispersion models and plume characteristics of previous studies are not necessarily true. This study collected more samples than existing studies which was intended to increase the statistical significance of results. These samples were collected both during normal daytime conditions and during stable conditions. For this study it was necessary to sample in fixed locations due to equipment constraints. In this study all data were not normalized though spikes in concentration caused by passing diesel vehicles were removed. Strengthening the variety of situations where UFP samples are collected may have a direct implication on future examinations for how UFP impacts health negative outcomes. Findings from the typically more rural, mountainous setting may also expand the potential health implications for those living in rural, geographically diverse settings rather than focusing solely on populated, urban areas.

Methodology

Sampling Methodology

The location of sampling was selected primarily with topography in mind. The sampling area was contained within a valley with an interstate running roughly perpendicular to the valley. The area is shown on the next page in figure 1. Figure 1 is annotated to show relevant sampling locations. The interstate is I-79 and is running north to south. This road was the source of diesel traffic and UFP. Route 221 was the sampling location and runs parallel to the valley and perpendicular to the interstate. The sampling area is rural with the notable exception of a natural gas drilling pad on Washington Road nearby. This pad would periodically attract significant truck traffic to route 221 and sampling was not conducted on days when this traffic was noticeable. Prevailing winds for the area run from west to east through the length of the valley. Due to the diluting impact that wind has on UFP, it was decided that samples would only be collected on days with low wind speed. Any day with wind speed higher than 5mph was excluded from the study as a potential sample date. This wind speed information was collected from measurements conducted by the WeatherUnderground weather monitoring station in Waynesburg, Pennsylvania a few miles south of the sampling location. Similarly, no samples were collected on days where it rained based on the association between rain and significantly reduced particulate matter concentrations. For all sampling areas, the distance perpendicular from the interstate was used and not the distance along route 221. All distances were determined with Google Maps distance measuring and GPS coordinates collected at the sampling site. Photographs of each sampled location are included in figures 2-10. This includes each of the four distances on both sides of the interstate and the hilltop area found nearby.

Two samplers were used concurrently for each sample. The machines used for collection of all samples were P-Trak Ultrafine Particle Counters (TSI Model 8525). A photograph of one of the samplers used is shown in figure 11. These samplers record the concentration of particles in

Figure 1: Topographic map of the sampling area. A–(100m East) B–(200m East) C–(300m East) D–(600m East) E–(100m West) F–(200m West) G–(300m West) H–(600m West) I–(Hilltop Background)

Figure 2: 100m East. The sampler was placed on the guardrail that is visible in the photograph and left there for the 200m, 300m, and 600m East samples. The interstate is visible in the background.

Figure 3: 200m East. The sampler was placed on the fencepost next to the stop sign in the photograph for 5 minutes. The interstate and the 100m East location are visible in the background. To the left is a staging area for the well-pad nearby.

Figure 4: 300m East. The sampler was placed on the fencepost to the left of the gate in the photograph for 5 minutes. The interstate is visible in the background.

Figure 5: 600m East. The sampler was placed on the guardrail shown in this photograph for 5 minutes. The interstate is barely visible in the background.

Figure 6: 100m West. The sampler was placed on the guardrail on the right side of the road in the photograph and left there for the 200m, 300m, 600m East, and hilltop samples. The interstate is barely visible in the background.

Figure 7: 200m West. The sampler was placed on top of a car that was parked to the left side of the photograph for 5 minutes. This location was a relatively busy intersection. The interstate is not visible from this location and is behind the photographer. The road where sampling took place is the one that continues out of the background of this photograph.

Figure 8: 300m West. The sampler was placed on top of a car that was parked in the small parking lot shown in the photograph. The interstate is not visible from this location and is behind the photographer.

Figure 9: 600m West. The sampler was placed on top of a car parked in the fenced in area to the left side of the photograph. The interstate is not visible from this location and is behind the photographer.

Figure 10: Hilltop Background. The sampler was placed on top of a car parked on the left-hand side of the photograph. The interstate is not visible from this location and is to the left-hand side of the photograph.

Figure 11: One of the two P-Trak particle counters used in this study. The second sampler is functionally identical with only minor differences in flow control technology and the color of the outer casing.

the range of 0.02-1 μ m. These instruments function based on the condensation particle counting technique using isopropyl-alcohol. The condensation particle counting technique involves using isopropyl-alcohol to artificially grow the size of particles and render them easier to count with optical scanners. The aerosol to be sampled is pulled into the instrument via a small pump where it is then mixed with an alcohol vapor. For these instruments this was isopropyl-alcohol. The new mixture then passes into a condenser where the saturated alcohol is forced to condense. The particles in the original aerosol act as nucleation sites for the condensing alcohol and the alcohol increases the particles' diameter. The artificially larger particles then move to an optical sensor to be counted. The particles pass through a laser beam and cause distortions in the light that are measured and counted. These instruments were selected because of their handheld size, fast response time, and battery power capabilities. There is no calibration procedure for these devices since they are calibrated by the manufacturer (TSI). Both devices were calibrated by the manufacturer prior to the beginning of sampling. Calibration was verified by concurrently sampling a variety of locations with both instruments. The results of this sampling process were compared and found to be almost identical. The results of this process are shown in figure 12.

Figure 12: Correlation between the concentration readings of the two instruments used in this study. The slope is almost exactly 1 and shows that the instrument span is nearly identical. The mobile instrument consistently read 152 pt/cc higher than the stationary instrument as evidenced by the intercept of the fitted line.

The spans of both instruments were functionally identical as evidenced by the slope of the regression curve being approximately equal to one. The zero of both instruments was slightly different with the mobile instrument reading roughly 150 particles per cubic centimeter (pt/cc) higher than the stationary instrument in the same environment. This is a small error relative to the typical concentrations of around 5000pt/cc. It was assumed that the stationary instrument was more accurate due to its more recent calibration therefore the concentration readings of the mobile instrument were corrected accordingly by subtracting 150pt/cc from the raw readings. This resulted in instrument readings that were comparable to one another and accurate to within roughly 10pt/cc.

The first sampler was left 100m from the interstate in every sample. On every sample date, the stationary device used at 100m was always the same sampler, e.g. the darker colored instrument. The other instrument, the lighter colored instrument, was always used to measure the concentration of UFP at the further distances. The instrument at 100m was set to continuously record particle concentration every second for the duration of the sampling on the eastern side of the interstate. It remained stationary and actively sampling for roughly 30 minutes while the other 5-minute samples were collected with the other instrument. The mobile instrument was then taken to 200m, 300m, and 600m away from the interstate to collect samples on the eastern side of the interstate. These samples were collected for five minutes each. For the length of this five minutes, the instrument continuously collected a sample every second. For each sampling distance the sampler was placed on a stable surface roughly 2-4 feet off the ground. The samplers were also placed as close to Route 221 as possible and oriented towards the road. During each of these five-minute periods the truck traffic passing along the interstate was recorded by hand. This was strictly the number of heavy-duty diesel motor vehicles that passed along the interstate above Route 221. Once this process had been completed for the eastern side of the interstate it was repeated for the western side of the interstate. The traffic on the interstate on this side was not visible so it was impractical to count heavy-duty vehicles. For this reason, the data on the western side of the interstate includes only particle concentrations. Finally, the mobile device was taken to a nearby location on top of the surrounding mountain range to collect a background reading. Each collection of samples at all the various distances was repeated 40 times.

Data Analysis

Raw data were stored in the sampling instruments at the time of sampling. These data were later uploaded from the instruments' memory to a computer. At this stage specific software provided by TSI was necessary to interface with the instruments. The sampling concentrations were exported from this software into Microsoft Excel where the entirety of the following analysis was conducted. The first step was to correct the erroneous time stamps of the sampling data. Due to the handheld nature of the samplers and somewhat frequent battery changes the time stamps that were recorded by the software were inaccurate. This error ranged from a few minutes to half of an hour. The starting time of each sample was recorded at the time of sampling in a field notebook using an Apple I-Phone to determine the time, and these handwritten times were used to correct the erroneous time stamps. The starting time was manually entered into the Excel sheet where an increment of one second was repeatedly added. This new string of times replaced the older times.

Next, it was necessary to align the samples with respect to time. Samples were collected at two different distances simultaneously and this needed to be expressed correctly by the data after replacing all time stamps. This was done by taking a time stamp for a specific mobile sampling point and searching through the appropriate collection of times for the stationary sampler. The two points were then considered paired for further calculations. This process was repeated for each mobile sample for all 40 collection periods.

Next, it was necessary to isolate the relevant sections of the stationary samples. Stationary samples ran continuously and consequently include measurements for time periods where no mobile sampling was occurring. These unpaired segments of data were not useful for analysis and were ignored. Only points that were paired were included for the analysis and the rest of the data collected by the stationary sampler was ignored. This resulted in only segments of time that contained samples from both samplers being included for analysis.

A simple, arithmetic average was calculated for each sampler at each distance from the paired data. These averages were used to generate a variety of box plots to characterize various aspects

of the data. This includes sorting by distance, traffic level, and inversion status of the samples. A plot of inversion status vs. location data normalized to traffic levels was also included. This was done to illustrate the significance of traffic count to the results of sampling. This was accomplished by dividing the sample concentrations by the average level of traffic for that period.

Sorting by distance and inversion status was relatively simple. Sorting by traffic status was slightly more challenging. All traffic data was transcribed from the handwritten samples recorded on location. The total amount of traffic for a given sampling day was represented by three individual five-minute counts of truck traffic. The traffic on the eastern side of the road was recorded at three locations but not on the western side of the road due to visibility issues. These three counts were averaged for each sampling day resulting in 40 average counts of truck traffic per five-minute sampling period. The global average of the averages was calculated and the samples were sorted into bins based on this average. The global average that determined traffic bin was found to be 48.75. Any sample with an average of 48.75 or higher was considered high traffic and any sample with an average lower than 48.75 was considered low traffic. The sorted bins were the only thing considered when sorting samples based on traffic levels. A plot of the sample averages is shown below in figure 13.

Figure 13: A plot of the average count of diesel vehicles compared to sample ID. Of note: samples 1-20 were during weather inversions and samples 21-40 were not.

Results and Discussion

Results

The plots that were generated are shown below. Figure 14 shows the data sorted only by location. Data included for this graph include all mobile data and the corresponding stationary data collected at 100m. This plot shows that the eastern side of the road had minor variation between the stationary and mobile samples that were collected concurrently. This is not what is described by other studies that suggest that the mobile sample readings should be significantly lower than the stationary readings. This may not necessarily be true for the 200m reading but would be considered the case for the 300m and 600m readings. The western side of the interstate exhibits behavior that is more in line with previous studies. This side of the road is the upwind side and the mobile readings decrease rapidly between 200m and 300m. The hilltop background also appears to decrease albeit with more variation than the other two locations. Figure 15 shows the same plot but with the further classification of points into either inversion weather conditions or non-inversion condition. This plot generally shows the same thing as the previous one. It is notable though that the variation of the non-inversion samples generally appears to be much larger than their corresponding counterparts. It is also notable that there appears to be trivial difference between the inversion and non-inversion samples. This is unexpected. The literature reviewed for this document strongly suggest that weather inversions are a significant factor in particulate matter plumes. Literature suggests that the plume length during weather inversion events is significantly increased and would correlate to an increase in concentrations both close to and further away from the interstate. This is not the case in this study. Concentrations readings during inversion events are not noticeably different from non-inversion samples. Figure 16 also supports this conclusion. In fact, it shows that the noninversion concentrations are generally a bit higher than inversion concentrations if they are different at all. Finally, Figures 17 and 18 show the data sorted into high and low traffic bins. These plots show results like those of the plots sorted by inversion status. The first shows that the downwind side of the interstate shows insignificant variation and the upwind side has a small drop off in concentration. The second is nearly identical to the corresponding inversion-sorted plot. In this case however the result is expected. Higher traffic

count should lead to higher concentrations. However, the similarity of figures 16 and 18 suggest that there is some strong covariance between traffic level and inversion status. This was investigated by normalizing the measured concentrations based on traffic level as described in the data analysis section of methodology. This plot is shown in figure 19. In this plot the inversion status of a sample had almost no effect on the average concentration. This suggests that traffic level is the principal factor effecting the particulate matter plume in this study and that there is indeed a strong covariance between the two classifications. It is believed that this covariance arises from the fact that there is more truck traffic during the day. Inversions occur at hours such as 5:00am or 9:00pm where heavy truck traffic is reduced. This could explain why results sorted by inversion status appear so similar to results sorted by traffic level. The two factors are linked by the simple fact that truck drivers in general prefer to do their driving during the day and not during inversions.

Figure 14: Average concentration readings segregated by location and instrument used. All stationary readings (Blue) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Figure 15: Average concentration readings segregated by inversion status, location, and instrument used. All stationary readings (Blue & Grey) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Figure 16: Average concentration readings segregated by inversion status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

Figure 17: Average concentration readings segregated by traffic status, location, and instrument used. All stationary readings (Blue & Grey) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Figure 18: Average concentration readings segregated by traffic status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

Figure 19: Average concentration readings divided by the number of trucks counted during the sample. Results are segregated by inversion status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

All results listed above were conducted with data that included significant spikes in measured concentration. Confounding traffic along route 221 caused these large spikes in the readings of both instruments periodically. These spikes cause the average concentrations to be higher than they should be and could cause significant error within the analysis. In an effort to control this variance, these spikes were removed through manual inspection of the data. This method is far from ideal and should be replaced with an algorithmic approach appropriate to the data. Unfortunately, prior to the writing of this document the simple, manual removal of spikes was all that was possible.

All previous graphs were repeated for the new data set with spikes removed and are shown below. Each graph was then analyzed with either a Student's t-test or an ANOVA. Cases where only two sample means were compared were analyzed with t-tests with assumed unequal variance and an alpha value of 0.05. An example of this would be figure 20 below. Cases where more than two means were compared were analyzed with a single factor ANOVA with an alpha value of 0.05. An example of this would be figure 21 below. The results of these analyses are included below in conjunction with the updated graph of the appropriate data. In general, the results of the graphs of data with no spikes and statistical analysis were consistent with the graphs that included

data spikes and the insights previously discussed. All statistical tests were conducted within Microsoft Excel.

Figure 20: Average concentration readings after smoothing segregated by location and instrument used. All stationary readings (Blue) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Table 1: Results of t-Tests with two-samples assuming unequal variances. Corresponding data is shown above in Figure 20. Table 1 continued on the next page.

600m East	<i>Stationary</i>	<i>Mobile</i>
Mean	5997.381764	5523.832199
Variance	1084829639	9546780768
Calculated t Stat	0.4072582865	6992926.053
P(T<=t) two-tail	0.3268178656	
t Critical two-tail	0.991134993	
No significant Difference		
200m West	<i>Stationary</i>	<i>Mobile</i>
Mean	5986.420623	7012.994181
Variance	65867932946	14813658058
Calculated t Stat	21.496189549	8147025.926
P(T<=t) two-tail	0.2891068137	
t Critical two-tail	0.2997642578	
No significant Difference		
300m West	<i>Stationary</i>	<i>Mobile</i>
Mean	6184.493882	5466.615756
Variance	11419336.32	12736669.04
Calculated t Stat	0.918230815	
P(T<=t) two-tail	0.361365402	
t Critical two-tail	1.991254395	
No significant Difference		
600m West	<i>Stationary</i>	<i>Mobile</i>
Mean	6302.851378	5092.413671
Variance	11745062.64	7253463.356
Calculated t Stat	1.742598635	
P(T<=t) two-tail	0.085673392	
t Critical two-tail	1.993463567	
No significant Difference		
Hilltop Background	<i>Stationary</i>	<i>Mobile</i>
Mean	6381.192655	5565.894535
Variance	14540148.54	10627361.99
Calculated t Stat	0.953392041	
P(T<=t) two-tail	0.343923577	
t Critical two-tail	1.997137908	
No significant Difference

Figure 21: Average concentration readings after smoothing segregated by inversion status, location, and instrument used. All stationary readings (Blue & Grey) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Table 2: Single factor ANOVA results. Corresponding data shown above in figure 21. Table 2 continued on next 2 pages.

200m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	101375.609	5068.780452	3780958.352		
Inversion Mobile	20	86705.83392	4335.291696	2454206.759		
Non-Inversion Stationary	20	160501.7008	8025.085039	35578726.99		
Non-Inversion Mobile	20	132560.489	6628.024452	11501991.99		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	51122115.99	3	17040705.33	2.199149027	0.095026173	2.72494392
Within Groups	588906703.9	76	7748772.42			
Total	640028819.9	79				
No Significant Difference						

300m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	99824.60136	4991.230068	3842785.587		
Inversion Mobile	20	93026.75703	4651.337852	2775327.809		
Non-Inversion Stationary	20	127536.0121	6376.800607	14456413.63		
Non-Inversion Mobile	20	128524.4737	6426.223685	9920562.657		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	162659805.6	3	54219935.19	4.067826023	0.009791186	2.72494392
Within Groups	1013001798	76	13328971.02			
Total	1175661603	79				
Significant Difference						
600m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	94045.60963	4702.280482	4141290.117		
Inversion Mobile	20	99194.16748	4959.708374	4137304.031		
Non-Inversion Stationary	20	145849.6609	7292.483046	17489345.34		
Non-Inversion Mobile	20	121759.1605	6087.958025	14788408.6		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	84305930.86	3	28101976.95	2.771647673	0.047227005	2.72494392
Within Groups	770570613.7	76	10139087.02			
Total	854876544.6	79				
Significant Difference						
200m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	121581.9852	6079.09926	4974147.79		
Inversion Mobile	20	149540.7237	7477.036185	12403649.21		
Non-Inversion Stationary	19	111888.4191	5888.864164	13252280.18		
Non-Inversion Mobile	20	130979.0435	6548.952177	20463580.65		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29776280.95	3	9925426.983	0.777426489	0.510237621	2.72658916
Within Groups	957527218.4	75	12767029.58			
Total	987303499.4	78				
No Significant Difference						

300m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	121863.4551	6093.172756	4373817.089		
Inversion Mobile	20	97872.6511	4893.632555	2824242.097		
Non-Inversion Stationary	19	119331.8063	6280.621382	19471660.83		
Non-Inversion Mobile	20	120791.9791	6039.598957	22628268.57		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	23651262.29	3	7883754.097	0.644666294	0.588728026	2.72658916
Within Groups	917190122.3	75	12229201.63			
Total	940841384.6	78				
No Significant Difference						

600m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	20	124341.343	6217.067148	8014561.998		
Inversion Mobile	20	93725.96362	4686.298181	2602350.013		
Non-Inversion Stationary	19	121469.8608	6393.150568	16318533.26		
Non-Inversion Mobile	20	109970.5832	5498.52916	11939117.32		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	35831557.68	3	11943852.56	1.240192758	0.30118235	2.72658916
Within Groups	722298155.8	75	9630642.077			
Total	758129713.5	78				
No Significant Difference						

Hilltop Background						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Inversion Stationary	15	86074.3024	5738.286827	15833467.57		
Inversion Mobile	15	85114.98632	5674.332422	7274519.425		
Non-Inversion Stationary	19	130886.2479	6888.749888	13725653.59		
Non-Inversion Mobile	20	109691.3224	5484.566119	13640966.73		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	22867115.76	3	7622371.922	0.59711119	0.619172218	2.74591527
Within Groups	829751950.4	65	12765414.62			
Total	852619066.2	68				
No Significant Difference

Figure 22: Average concentration readings after smoothing segregated by inversion status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

Table 3: Results of t-Tests with two-samples assuming unequal variances. Corresponding data is shown above in Figure 22.

Stationary	Inversion	Non-Inversion
Mean	5548.940042	6746.056675
Variance	6128892.13	18333617.71
Calculated t Stat	-2.820023902	
P(T<=t) two-tail	0.005246768	
t Critical two-tail	1.970956301	
Significant Difference		
Mobile	Inversion	Non-Inversion
Mean	5223.563579	6101.978939
Variance	5633361.208	14528033.58
Calculated t Stat	-2.302862575	
P(T<=t) two-tail	0.022164781	
t Critical two-tail	1.970153643	
Significant Difference

Figure 23: Average concentration readings after smoothing segregated by traffic status, location, and instrument used. All stationary readings (Blue & Grey) were collected at 100m on the corresponding side of the interstate. The stationary samples shown are the corresponding data for the mobile distance that is labeled on the X-axis.

Table 4: Single factor ANOVA results. Corresponding data shown above in figure 23. Table 4 continued on next 2 pages.

200m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	108799.7592	5180.940915	7679899.738		
Low Traffic Mobile	21	112433.1938	5353.961608	7902238.288		
High Traffic Stationary	19	118560.8543	6240.044963	11227548.68		
High Traffic Mobile	19	109118.037	5743.054578	6287177.875		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	13120981.47	3	4373660.492	0.530218602	0.662904634	2.72494392
Within Groups	626907838.4	76	8248787.348			
Total	640028819.9	79				
No Significant Difference						

300m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	121459.8894	5783.804256	22184536.52		
Low Traffic Mobile	21	106628.9026	5077.566791	9215145.7		
High Traffic Stationary	19	140417.4205	7390.39055	20321888.44		
High Traffic Mobile	19	112637.4204	5928.285282	7011776.147		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	55661996.21	3	18553998.74	1.259021784	0.294502205	2.72494392
Within Groups	1119999607	76	14736836.94			
Total	1175661603	79				
No Significant Difference						
600m East						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	107521.7098	5120.081419	10661129.9		
Low Traffic Mobile	21	114276.0361	5441.716003	10208318.14		
High Traffic Stationary	19	132373.5607	6967.029513	12823559.82		
High Traffic Mobile	19	106677.2919	5614.594311	9325196		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	38809978.97	3	12936659.66	1.204786687	0.313818021	2.72494392
Within Groups	816066565.6	76	10737717.97			
Total	854876544.6	79				
No Significant Difference						
200m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	132261.943	6298.18776	10510640.19		
Low Traffic Mobile	21	155982.4943	7427.737823	16542586.44		
High Traffic Stationary	18	101208.4613	5622.692297	6986301.121		
High Traffic Mobile	19	124537.273	6554.593314	16368571.32		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32837563.92	3	10945854.64	0.860103087	0.465666743	2.72658916
Within Groups	954465935.4	75	12726212.47			
Total	987303499.4	78				
No Significant Difference						

300m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	138000.5354	6571.454069	14305379.57		
Low Traffic Mobile	21	117010.0581	5571.90753	17318412.47		
High Traffic Stationary	18	103194.7259	5733.04033	8294947.122		
High Traffic Mobile	19	101654.5721	5350.240637	8326206.08		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	17479733.17	3	5826577.722	0.473263459	0.701828486	2.72658916
Within Groups	923361651.4	75	12311488.69			
Total	940841384.6	78				
No Significant Difference						

600m West						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	21	135018.4818	6429.451515	17217886.04		
Low Traffic Mobile	21	105453.7213	5021.605777	6515621.009		
High Traffic Stationary	18	110792.7219	6155.151219	5954435.516		
High Traffic Mobile	19	98242.82551	5170.675027	8463943.879		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29883178.85	3	9961059.617	1.025860661	0.386101285	2.72658916
Within Groups	728246534.6	75	9709953.795			
Total	758129713.5	78				
No Significant Difference						

Hilltop Background						
Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Low Traffic Stationary	17	96499.20155	5676.423621	10092658.11		
Low Traffic Mobile	17	105097.6325	6182.213679	9977568.624		
High Traffic Stationary	17	121366.6272	7139.213366	18419633.86		
High Traffic Mobile	18	90411.582	5022.865667	10961014.31		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	41587666.68	3	13862555.56	1.123278707	0.346198435	2.74591527
Within Groups	802175012.8	65	12341154.04			
Total	843762679.5	68				
No Significant Difference

Figure 24: Average concentration readings after smoothing segregated by traffic status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

Table 5: Results of t-Tests with two-samples assuming unequal variances. Corresponding data is shown above in Figure 24.

Stationary	<i>Low Traffic</i>	<i>High Traffic</i>
Mean	5871.059581	6468.081031
Variance	13070432.25	11876569.89
Calculated t Stat	-1.391105483	
P(T<=t) two-tail	0.165347231	
t Critical two-tail	1.968855173	
No significant Difference		
Mobile	<i>Low Traffic</i>	<i>High Traffic</i>
Mean	5712.461809	5630.901529
Variance	11284264.34	9318625.443
Calculated t Stat	0.210934951	
P(T<=t) two-tail	0.833095394	
t Critical two-tail	1.96869162	
No significant Difference

Figure 25: Average concentration readings after smoothing divided by the number of trucks counted during the sample. Results are segregated by inversion status and instrument used. All stationary readings were collected at 100m on the corresponding side of the interstate.

Table 6: Results of t-Tests with two-samples assuming unequal variances. Corresponding data is shown above in Figure 25.

Stationary	<i>Low Traffic</i>	<i>High Traffic</i>
Mean	428.1809782	397.0163691
Variance	51537.38559	110407.4776
Calculated t Stat	0.90206174	
P(T<=t) two-tail	0.367932247	
t Critical two-tail	1.969939406	
No significant Difference		
Mobile	<i>Low Traffic</i>	<i>High Traffic</i>
Mean	406.3237415	362.3125234
Variance	51146.62046	91708.35943
Calculated t Stat	1.368734368	
P(T<=t) two-tail	0.172277505	
t Critical two-tail	1.969237496	
No significant Difference		

Figure 20 shows average concentrations segregated by location similar to figure 14. No pair of samples showed statistically significant difference between sample averages. Table 1

contains the results of the t-tests that were conducted for this data set. Combined, this shows that for each pair of samples the concentration of samples collected at 100m were the same as the concentrations collected with the mobile instrument at further distances. Figure 21 is a version of figure 15 created with the data set with no spikes. Table 2 includes the results of single factor ANOVA tests for each distance bin. All results showed no significant difference between sample means except for the 300m and 600m distances on the eastern side of the interstate. This is likely due to the relatively low variance and mean values for the samples from the mobile sampler during inversion conditions. Figure 22 shows data sorted only by inversion status. Both pairs of sample means were found to be significantly different as seen in table 3. Non-inversion means were higher than inversion means for both cases. This is notable because it is the opposite of what is expected. Figure 23 shows the data sorted by traffic status and location. Table 4 shows that there were no significant differences between averages in this graph. Figure 24 shows the data sorted only by traffic status. Table 5 shows that there was no significant difference between low and high traffic days. Finally, figure 25 shows the data divided by the number of trucks counted in the given sample period. Table 6 shows that there was no difference within the two groups.

Discussion

The findings from this study suggest additional factors should be considered and measured to fully address the impact of UFP exposure near roadways. Concentrations on the upwind side of the interstate seem to decrease as distance from the interstate increases, however this occurs at a rate much slower than other studies have postulated and to a much less pronounced degree. Upwind concentrations were negligible even as close as 15m to the roadway in question in other studies [6,14]. In this study, it is nearly identical 200m away from the roadside. For comparison, the concentration in other studies would have dropped to well below 50% of the roadside peak concentration by 200m [6,14,18]. The other important observation is that while this study observed the expected drop off with increased upwind distance, it is nowhere near what was predicted. In the present study, the upwind concentrations could at best be described as a reduction from 10,000pt/cc to 5,000pt/cc (50%) all the way out at 600m and potentially beyond. This suggests plume characteristics different from those described by other studies. This could potentially be

caused by the fact that the closest measurement to the interstate in this study was 100m from the roadside. Since the concentration is expected to drop so rapidly, it is possible that this drop was missed entirely by the sampling in this study. This is not likely however, as the concentrations for 100m and 200m are nearly identical for the upwind side of the road and only show difference past the 200m point. This suggests that the plume is dispersing more slowly than expected. If the sharp drop had been missed entirely all measurements on the upwind side would be indistinguishable.

In these findings, downwind concentrations are equally disparate. They suffer from a similar problem as the upwind concentrations. Concentrations decrease with increasing downwind distance from the interstate as expected, however it is to a degree even less pronounced than the upwind concentrations. Concentrations at all distances on a side of the interstate show negligible variation. This again suggests plume characteristics different from those described in previous studies. It is even less likely that this set of data were influenced by the sampling of points strictly further than 100m. The spatial extent of downwind plumes is generally on the order of 100m-400m for particulate matter [35]. The sharpest gradient of the plume may have been missed but it is exceedingly unlikely that the concentration fell to background levels in less than 100m downwind.

As noted in previous studies, these findings illustrate a strong link between increased heavy vehicle traffic and measured UFP concentrations. This study shows an increase in measured concentration of UFP with increasing traffic volume. There is little reliable information regarding regressions of truck traffic to particle counts so it is unclear if the extent of difference is the same as within other studies.

The effects of weather inversions are reduced within the data collected for this study. In fact, they are reversed from what is expected. Previous literature suggests that weather inversions lower atmospheric mixing and directly lead to increased concentration of particulate matter [6,14]. This study seems to suggest the opposite trend. This is likely caused by the covariance of traffic flow and inversion status as previously discussed. In this study, inversion periods imply low traffic and traffic appears to be a more significant cause of particulate matter emission.

The hilltop background reading is not a true background. It is relatively close to the interstate and does not represent a background level far from the roadside. Instead, this measurement was taken at the top of the southern side of the valley. This measurement shows that

moving up the side of the valley does not have any significant impact on the measured concentrations. Concentrations at the base of the valley are comparable to concentrations at the top of the valley.

Some previous studies have suggested that dilution is the primary cause of diminishing UFP concentrations while others suggest that agglomeration is a primary cause [19,21,36]. Results of this study suggest that dilution is the primary dispersal mechanism for UFP near roadways. If agglomeration or coagulation were dominant, then UFP concentrations should drop significantly as distance from the source increases regardless of weather conditions or traffic volume. This is not what was seen in this study. Bulk mixing of the contaminated air with fresh air is what causes the concentration gradient. In this study it is theorized that the surrounding terrain impedes fresh air from reaching the highway and therefore indirectly impedes dilution.

Taken together, these conclusions suggest that previous plume models are not applicable to this study. For some reason, they have broken down and no longer accurately describe what is happening. It is believed that this is due to the topography of the region. It is believed that the valley where sampling took place had a direct effect on the concentrations of particulate matter collected, that the valley “filled up” with particulate matter that was emitted from the interstate. It has been seen that “street canyons” where a road passes in between a canyon of tall buildings can affect the mixing properties of aerosols within urban environments [21]. It is believed that a similar phenomenon is occurring with respect to natural canyons. The walls of the valley or canyon perhaps reduce the effect of wind on the mixing of the air within the valley and cause increased concentrations. More than just increased concentration though, it seems that plume shape is affected as well. Data from this study would suggest that the plume consistently extends beyond 600m in both directions of the valley with little to no drop off. This could imply a plume where concentrations are elevated for several kilometers following the contour of the valley.

Low traffic levels seen in this study could also be responsible for the lack of concentration gradient. Traffic volume in this study is likely significantly lower than similar studies performed in urban areas. The results of this study could simply be an indication that particulate matter is not a significant concern in rural areas. If this is the case, then further research should be conducted on the actual effects of topography on UFP concentrations near roadways. Regardless of the true

cause, the difference from expected results exhibited within this study is certainly cause for further investigation.

Limitations

While significant efforts were taken to address limitations from previous studies to expand our knowledge of UFP exposure, this study is not without limitations. It is important to note that the apparent increased size of the particulate matter plume could be because all samples were collected on days with minimal wind and no rain. In previous studies this condition is usually exclusive to weather inversions. Samples taken during the day would not be excluded based on high wind speed and the effects of wind speed would be included in the study. For this study, this wind speed analysis was not a desired objective and many potential sampling days were excluded due to high wind or other inclement weather. Due to this it is likely that this study represents a worst-case scenario that is only applicable to weather inversion samples in other studies. Higher wind speed or rainy weather would very likely depress the concentrations represented within this study and could lower concentrations, shorten plume length, and cause more significant differences between weather inversion samples and non-inversion samples as was expected. In short, despite labeling samples collected during sunrise and sunset as weather inversion/stable samples it is likely that every sample that was collected was under stable atmospheric conditions.

No Scanning Mobility Particle Sizer (SMPS) was used in this study. This is generally done to show that diesel emissions are the dominant source for the particulate matter in the area. Burning diesel fuel results in a general particle distribution and verifying that this distribution is dominant in the area can show the diesel traffic is likely the source of the particulate matter. At the time of data collection, a SMPS was not available so it was assumed that the UFP in the area was generated directly from diesel traffic.

The data in this study is highly variable. Diesel vehicles would occasionally pass along route 221 during a sample and cause large spikes within the measured particulate matter concentration. These spikes typically cause the measured concentration to go from 3,000pt/cc-7,000pt/cc to over 100,000pt/cc for a brief period. This is likely why the upper error bars of the

plots contained within this study are significantly larger than the lower error bars in almost every case. This is normally corrected by using a moving average of points to smooth out the exceedingly large spikes however the short five-minute sampling period of samples did not leave a large enough number of data points to perform this smoothing adequately. It was attempted to smooth the data through manual inspection and removal of large spikes in concentration. This introduces human error to the study. Ideally, an algorithmic method of removing spikes should be used to ensure that this error is minimized.

It was desired that the sampling of all distances from the roadway be performed concurrently. This was simply not possible due to equipment constraints. This directly contributes to the previously mentioned limitation since it was required that the samplers be operational for a relatively longer period of time. Concurrent sampling could result in one 5-10-minute period of data collection per side of the interstate instead of 3-4 five-minute samples per side.

A natural gas well-pad near the sampling location and a staging area for diesel vehicles adjacent to the 200m sampling location on the eastern side of the interstate would routinely cause increased levels of traffic along route 221. Samples were not collected on days where this confounding was apparent however it is possible that error was introduced from this traffic. Any error from this traffic should be controlled by the removal of spikes in the data but as previously discussed this removal method was also a limitation of the study. This traffic could contribute to the high variance of the sample data.

Statistical assumptions of tests used in this study were likely violated. One of the main assumptions of the t-test and ANOVA are that data are independent. This is very likely not the case due to the non-simultaneous sampling of different distances. The violation of the assumption of independence could negate the conclusions drawn from statistical testing used in this study. It is also not known if the distributions of concentration values are normally distributed. This was assumed for analysis, but it is possible that the data follows another distribution and should consequently be handled differently.

Conclusions

The purpose of this study was to examine the potential effects of topography on the distribution of UFP near a roadway. 40 samples were collected within a valley in the Appalachian Mountains in southern Pennsylvania. This valley runs perpendicular to a 4-lane interstate and contains a small community. It was hypothesized that the differing topography of the sample area would lead to results that differed from past studies. It was found that the concentrations of particulate matter within the sample area remained elevated for far longer than would be expected from comparable literature. Typically, the concentration of UFP degrades to less than 50% of the roadside peak somewhere within 100m-400m downwind of an interstate but in this study, it was not seen to decrease significantly in over 600m. The hypothesis was considered confirmed, however it is not clear if the results of this study were directly caused by the topography of the area, though this is strongly believed. This study indicates that the effects of topography on the distribution of particulate matter near roadways should be more closely examined in the future. In this study the concentration of particulate matter was not observed to fall below 50% of the roadside peak value within 600m. This could potentially pose a serious health risk to individuals living in similar areas around the country since previous studies suggest that the particulate matter concentration would be reduced to acceptable levels far earlier than in reality. It is desirable that a future study verify the results presented herein with similar topography from a different location. It would also be desirable for a future study to determine the distance at which particulate matter concentrations fall below 50% of roadside peak for various topologies to assess how topography of the area could potentially change how particulate matter affects mountainous communities. Differing topological conditions should also be examined; of note is the case where a highway runs parallel to a valley. If valleys do have a measurable effect on particulate matter concentrations near roadways, then a large roadway running along the bottom of a valley could potentially exhibit extremely high UFP concentrations and pose a serious health risk to occupants of the valley. Further studies should also be conducted to characterize how wind speed and weather conditions affect particulate matter concentrations within mountainous regions near highly trafficked roadways. It is believed that wind and rain will have effects like in previous literature however there could be a more pronounced or less pronounced effect in these areas. Mechanisms of dispersal could potentially be examined as well since there appears to be a marked lack of mixing within valleys.

Bibliography

- 1) Brauer, M., Lencar, C., Tamburic, L., Koehoorn, M., Demers, P., & Karr, C. (2008). A Cohort Study of Traffic-Related Air Pollution Impacts on Birth Outcomes. *Environmental Health Perspectives*, 116(5), 680-686. doi:10.1289/ehp.10952
- 2) Brook, R. D. (2002). Inhalation of Fine Particulate Air Pollution and Ozone Causes Acute Arterial Vasoconstriction in Healthy Adults. *Circulation*, 105(13), 1534-1536. doi:10.1161/01.cir.0000013838.94747.64
- 3) Brugge, D., Durant, J. L., & Rioux, C. (2007). Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks. *Environmental Health*, 6(1). doi:10.1186/1476-069x-6-23G
- 4) Brunekreef, B., Janssen, N. A., Hartog, J. D., Harssema, H., Knape, M., & Vliet, P. V. (1997). Air Pollution from Truck Traffic and Lung Function in Children Living near Motorways. *Epidemiology*, 8(3), 298. doi:10.1097/00001648-199705000-00012
- 5) Capaldo, K., & Pandis, S. (2001). Lifetimes of Ultrafine Diesel Aerosol, Report for the University of Minnesota and the Coordinating Research Council under the E-43 Project Diesel Aerosol Sampling Methodology. Carnegie Mellon University, Pittsburgh, PA.F
- 6) Choi, W., He, M., Barbesant, V., Kozawa, K. H., Mara, S., Winer, A. M., & Paulson, S. E. (2012). Prevalence of wide area impacts downwind of freeways under pre-sunrise stable atmospheric conditions. *Atmospheric Environment*, 62, 318-327. doi:10.1016/j.atmosenv.2012.07.084F
- 7) Choi, W., Hu, S., He, M., Kozawa, K., Mara, S., Winer, A. M., & Paulson, S. E. (2013). Neighborhood-scale air quality impacts of emissions from motor vehicles and aircraft. *Atmospheric Environment*, 80, 310-321. doi:10.1016/j.atmosenv.2013.07.043
- 8) Ciccone, G., Forastiere, F., Agabiti, N., Biggeri, A., Bisanti, L., Chellini, E., ... Viegi, G. (1998). Road traffic and adverse respiratory effects in children. SIDRIA Collaborative Group. *Occupational and Environmental Medicine*, 55(11), 771-778.
- 9) Donaldson, K., Li, X., & Macnee, W. (1998). Ultrafine (nanometre) particle mediated lung injury. *Journal of Aerosol Science*, 29(5-6), 553-560. doi:10.1016/s0021-8502(97)00464-3
- 10) Fraser, M. P., Buzcu, B., Yue, Z. W., Mcgaughey, G. R., Desai, N. R., Allen, D. T., ... Harley, R. A. (2003). Separation of Fine Particulate Matter Emitted from Gasoline and

- Diesel Vehicles Using Chemical Mass Balancing Techniques. *Environmental Science & Technology*, 37(17), 3904-3909. doi:10.1021/es034167e
- 11) Fruin, S. A. (2003). Characterizing black carbon inside vehicles: Implications for refined exposure assessments for diesel exhaust particulate matter (Doctoral dissertation)
 - 12) Hitchins, J., Morawska, L., Wolff, R., & Gilbert, D. (2000). Concentrations of submicrometre particles from vehicle emissions near a major road. *Atmospheric Environment*, 34(1), 51-59. doi:10.1016/s1352-2310(99)00304-0
 - 13) Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., & Brandt, P. A. (2002). Association between mortality and indicators of traffic-related air pollution in the Netherlands: A cohort study. *The Lancet*, 360(9341), 1203-1209. doi:10.1016/s0140-6736(02)11280-3
 - 14) Hu, S., Fruin, S., Kozawa, K., Mara, S., Paulson, S. E., & Winer, A. M. (2009). A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours. *Atmospheric Environment*, 43(16), 2541-2549. doi:10.1016/j.atmosenv.2009.02.033
 - 15) Hu, S., Paulson, S. E., Fruin, S., Kozawa, K., Mara, S., & Winer, A. M. (2012). Observation of elevated air pollutant concentrations in a residential neighborhood of Los Angeles California using a mobile platform. *Atmospheric Environment*, 51, 311-319. doi:10.1016/j.atmosenv.2011.12.055
 - 16) Janssen, N. A., Brunekreef, B., Vliet, P. V., Aarts, F., Meliefste, K., Harssema, H., & Fischer, P. (2003). The Relationship between Air Pollution from Heavy Traffic and Allergic Sensitization, Bronchial Hyperresponsiveness, and Respiratory Symptoms in Dutch Schoolchildren. *Environmental Health Perspectives*, 111(12), 1512-1518. doi:10.1289/ehp.6243
 - 17) Kan, H., Heiss, G., Ross, K., Whitsel, E., Lurmann, F., & London, S. (2006). Traffic Exposure and Lung Function in Adults: The Atherosclerosis Risk in Communities Study. *Epidemiology*, 17(Suppl). doi:10.1097/00001648-200611001-00666
 - 18) Karner, A. A., Eisinger, D. S., & Niemeier, D. A. (2010). Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data. *Environmental Science & Technology*, 44(14), 5334-5344. doi:10.1021/es100008x
 - 19) Ketznel, M., & Berkowicz, R. (2004). Modelling the fate of ultrafine particles from exhaust pipe to rural background: An analysis of time scales for dilution, coagulation and

- deposition. *Atmospheric Environment*, 38(17), 2639-2652.
doi:10.1016/j.atmosenv.2004.02.020
- 20) Knox, E. G., & Gilman, E. A. (1997). Hazard proximities of childhood cancers in Great Britain from 1953-80. *Journal of Epidemiology & Community Health*, 51(2), 151-159.
doi:10.1136/jech.51.2.151
- 21) Kumar, P., Ketzel, M., Vardoulakis, S., Pirjola, L., & Britter, R. (2011). Dynamics and dispersion modelling of nanoparticles from road traffic in the urban atmospheric environment—A review. *Journal of Aerosol Science*, 42(9), 580-603.
doi:10.1016/j.jaerosci.2011.06.001
- 22) Künzli, N., McConnell, R., Bates, D., Bastain, T., Hricko, A., Lurmann, F., . . . Peters, J. (2003). Breathless in Los Angeles: The Exhausting Search for Clean Air. *American Journal of Public Health*, 93(9), 1494-1499. doi:10.2105/ajph.93.9.1494
- 23) Laden, F., Neas, L. M., Dockery, D. W., & Schwartz, J. (2000). Association of fine particulate matter from different sources with daily mortality in six U.S. cities. *Environmental Health Perspectives*, 108(10), 941–947.
- 24) Lin, S., Munsie, J. P., Hwang, S. A., Fitzgerald, E., & Cayo, M. R. (2000). Childhood Asthma Hospitalization And Residential Exposure To State Route Traffic. *Epidemiology*, 11(4). doi:10.1097/00001648-200007000-00184
- 25) McConnell, R., Berhane, K., Yao, L., Jerrett, M., Lurmann, F., Gilliland, F., . . . Peters, J. (2006). Traffic, Susceptibility, and Childhood Asthma. *Environmental Health Perspectives*, 114(5), 766-772. doi:10.1289/ehp.8594
- 26) Moon, S. (2015). Association of PM_{2.5} and Ultrafine Particle Concentrations with Diesel Exhaust from Truck Traffic in Morgantown, WV (Masters dissertation)
- 27) Pearson, R. L., Wachtel, H., & Ebi, K. L. (2000). Distance-Weighted Traffic Density in Proximity to a Home Is a Risk Factor for Leukemia and Other Childhood Cancers. *Journal of the Air & Waste Management Association*, 50(2), 175-180.
doi:10.1080/10473289.2000.10463998
- 28) Pey, J., Querol, X., Alastuey, A., Rodríguez, S., Putaud, J. P., & Dingenen, R. V. (2009). Source apportionment of urban fine and ultra-fine particle number concentration in a Western Mediterranean city. *Atmospheric Environment*, 43(29), 4407-4415.
doi:10.1016/j.atmosenv.2009.05.024

- 29) Polidori, A., Fine, P.M., Wilson, S., Koch, M., Ayers, E. (2009). Effect of Proximity to a Freeway with Heavy-duty Diesel Traffic on the Ambient Concentration of Criteria and Air Toxic Pollutants, 2009 National Ambient Air Monitoring Conference. The US Environmental Protection Agency, Nashville, TN.
- 30) Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. (2002). Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Jama*, 287(9), 1132. doi:10.1001/jama.287.9.1132
- 31) Stockman, J. (2008). Effect of exposure to traffic on lung development from 10 to 18 years of age: A cohort study. *Yearbook of Pediatrics*, 2008, 479-480. doi:10.1016/s0084-3954(08)70536-0
- 32) STPP. (2003). Clearing the Air. A Report of the Surface Transportation Policy Project (STPP).
- 33) Venn, A., Lewis, S., Cooper, M., Hubbard, R., & Britton, J. (2001). Living Near a Main Road and the Risk of Wheezing Illness in Children. *American Journal of Respiratory and Critical Care Medicine*, 164(12), 2177-2180. doi:10.1164/ajrccm.164.12.2106126
- 34) Vliet, P. V., Knape, M., Hartog, J. D., Janssen, N., Harssema, H., & Brunekreef, B. (1997). Motor Vehicle Exhaust and Chronic Respiratory Symptoms in Children Living near Freeways. *Environmental Research*, 74(2), 122-132. doi:10.1006/enrs.1997.3757
- 35) Zhou, Y., & Levy, J. I. (2007). Factors influencing the spatial extent of mobile source air pollution impacts: A meta-analysis. *BMC Public Health*, 7(1). doi:10.1186/1471-2458-7-89
- 36) Zhu, Y., Hinds, W. C., Kim, S., Shen, S., & Sioutas, C. (2002). Concentration and Size Distribution of Ultrafine Particles Near a Major Highway. *Journal of the Air and Waste Management Association*, 52, 1032-1042.